8th INTERNATIONAL CONGRESS OF SOIL SCIENCE

VIIIe CONGRÈS INTERNATIONAL DE LA SCIENCE DU SOL

VIII. INTERNATIONALER BODENKUNDLICHER CONGRESS

TRANSACTIONS
COMPTES-RENDUS
BERICHTE

II

BUCHAREST – ROMANIA 1964

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COMMISSION I

SOIL PHYSICS

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I. 1

RECHERCHES SUR L'INFLUENCE DE L'INTERACTION EAU — PHASE SOLIDE DU SOL SUR LE DRAINAGE DE L'EAU

S. ANDREI, RODICA SBENGHE[1]

L'idée fondamentale du présent rapport consiste dans le fait que dans les recherches sur le drainage de l'eau du sol, on doit observer non seulement les transferts de masse, mais aussi les transferts d'énergie, transferts qui, comme on le verra plus bas, sont conditionnés par l'interaction de l'eau et de la phase solide. Cela est nécessaire pour utiliser à l'étude de ces phénomènes l'équation du bilan d'énergie parallèlement à l'équation du bilan de masse.

Vu que dans les processus de la circulation de l'eau à travers le sol on peut distinguer deux aspects : la circulation sans modification de la teneur en eau (filtration) et la circulation avec modification de la teneur en eau (drainage — humectation), leur rapport définit les transferts d'énergie relatifs à ces aspects.

Ainsi, si l'on tient compte du fait que, pour les conditions isothermes la succion représente un potentiel négatif, il résulte que, pour transformer une quantité élémentaire d'eau $\mathrm{d}w$, retenue avec la succion s, en eau libre, il sera nécessaire que le milieu extérieur consomme un travail spécifique de drainage pour chaque unité de poids de matériel sec (Andrei, 1961) :

$$\mathrm{d}\mathfrak{L}_{dr} = s \cdot \mathrm{d}w, \tag{1}$$

qui correspond à la superficie hachurée de la figure 1 a.

Lorsque le sol subit un processus de drainage de la teneur en eau allant de w_1 à w_2, le travail spécifique de drainage sera

$$\mathfrak{L}_{dr} = \int_{w_1}^{w_2} s \cdot \mathrm{d}w, \tag{2}$$

auquel correspond la superficie $BCC'B'$ (fig. 1 a).

Si l'on observe le développement dans le temps du processus, on doit introduire la notion de puissance spécifique de drainage, respectivement d'humectation :

$$\mathfrak{Q}_{dr} = \frac{\mathrm{d}\mathfrak{L}_{dr}}{\mathrm{d}r}. \tag{3}$$

Des notions introduites ci-dessus, il résulte que la superficie de la boucle d'hystérésis $ABCB'A$ (fig. 1 b), comprise entre la branche de drainage et celle d'humectation, correspond à la quantité d'énergie ayant

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subi au cours du processus une transformation irréversible, c'est à dire

$$\Delta\mathcal{L} = \mathcal{L}_{dr} - \mathcal{L}_{u}, \tag{4}$$

où : $\mathcal{L}_{dr}$ représente le travail spécifique de drainage,
$\mathcal{L}_{u}$ — le travail spécifique d'humectation.

Il résulte donc que, pour effectuer un processus de drainage à une vitesse finie, on devra dépenser une énergie qui sera restituée en partie seulement

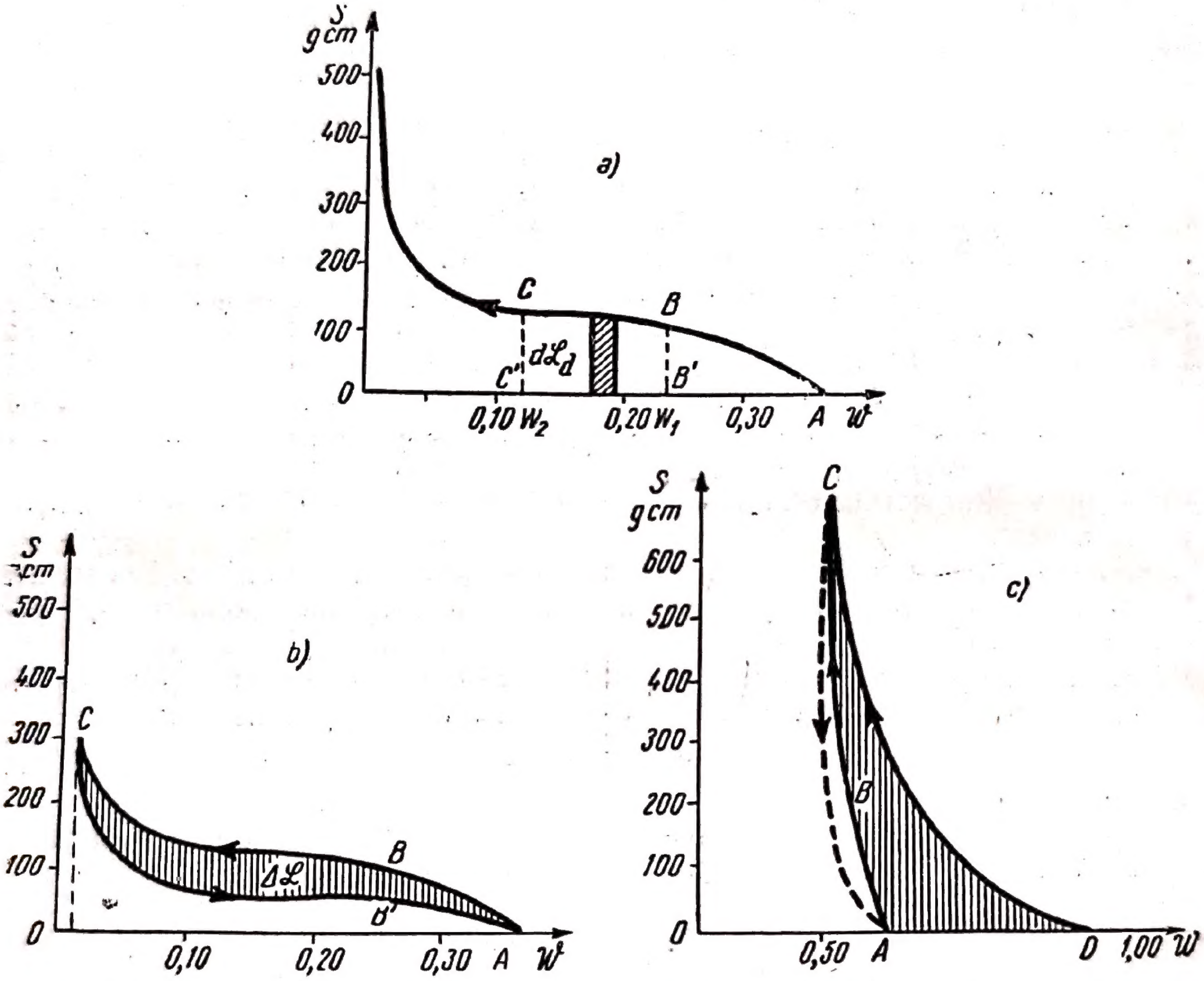

Fig. 1. Schémas pour la définition et l'interprétation graphique du travail spécifique de drainage-humectation : *a* — variation de la succion avec la teneur en eau et représentation graphique du travail élémentaire de drainage ; *b* — boucle d'hystérésis formée par les branches de drainage-humectation ; *c* — représentation du processus de drainage-humectation-drainage pour une argile active.

au cours du processus inverse d'humectation, ce qui d'ailleurs est en pleine concordance avec le deuxième principe de la thermodynamique. Conformément à ce même principe, plus la vitesse de développement du processus est grande — autrement dit plus le processus réel s'éloigne de celui quasi statique — plus la cote irréversible d'énergie augmentera en conséquence la superficie de la boucle d'hystérésis aussi. Ainsi, pour une argile trop active, l'énergie consommée lorsque le processus cyclique des variations de la succion

s'est étendu dans le domaine pF 1 — pF 2,5 a été de 3,75 gcm/g seulement, tandis que pour le domaine des variations pF 1 — pF 7 l'énergie a été de 6 700 gcm/g (Andrei, 1963).

Étant donné aussi, l'interprétation graphique du travail spécifique de drainage et d'humectation, on voit que la superficie hachurée *ABCD* de la figure 1 c, peut-être considérée comme représentant la valeur du travail spécifique dépensée pour la modification de l'état de compacité.

En effet, les données de la littérature (Croney, 1952) montrent que dans le cas de la répétition des cycles de drainage-humectation pour les ma-

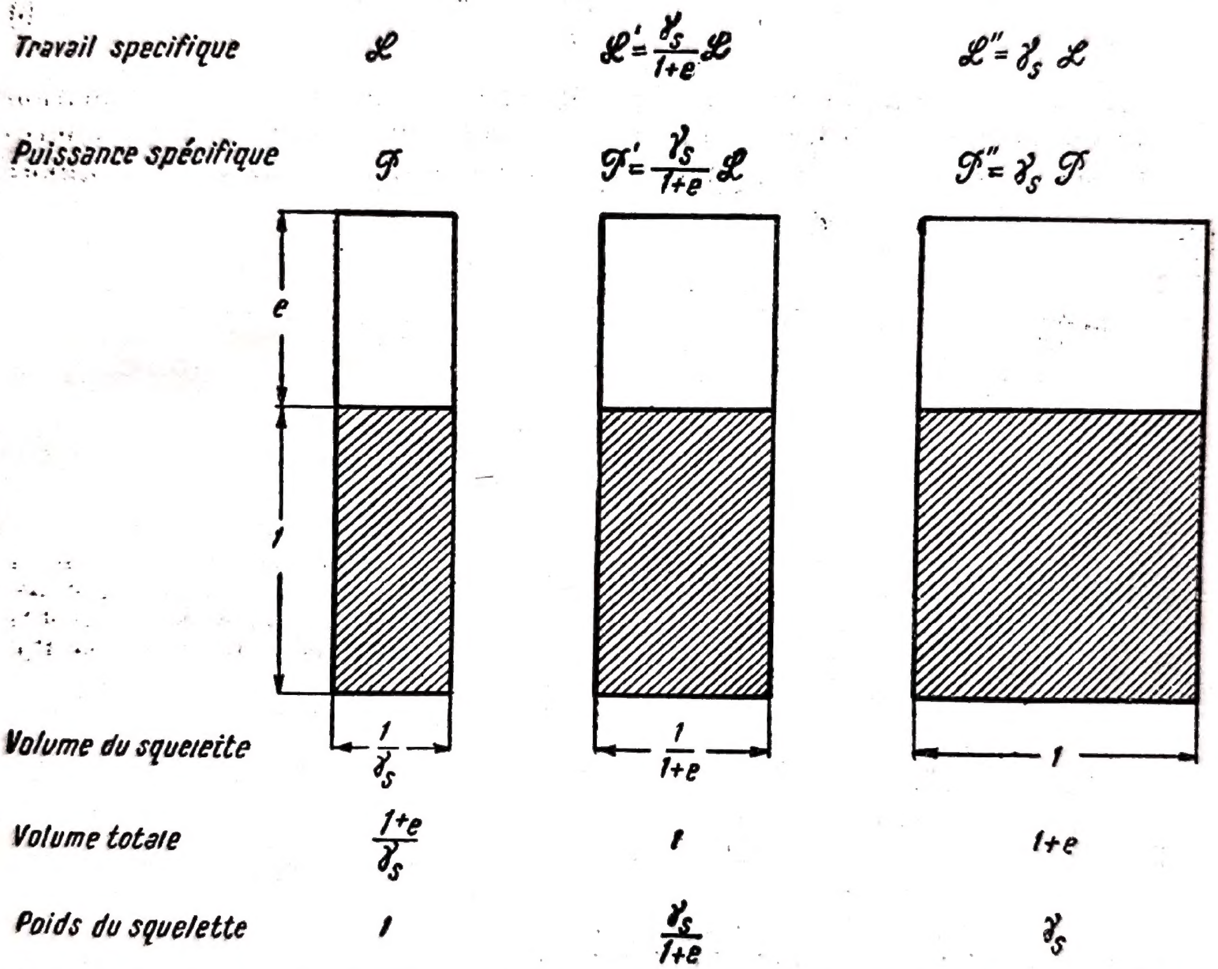

Fig. 2. Schéma pour la détermination des relations entre les travaux et les puissances spécifiques rapportées à l'unité de poids de la phase solide, à l'unité de volume total et à l'unité de volume du squelette solide.

tériaux à structure rigide, on obtient les mêmes branches de drainage et d'humectation et, par conséquent, on n'a pas dépensé d'énergie pour le compactage du matériel.

Lorsque le travail et la puissance spécifiques ne sont pas rapportés à l'unité de poids de la phase solide ($\mathcal{L}$, $\mathcal{P}$), mais au volume unitaire ($\mathcal{L}'$, $\mathcal{P}'$), ou au volume de la phase solide ($\mathcal{L}''$, $\mathcal{P}''$), on utilise les relations de transformation de la figure 2.

En utilisant les notions de travail et de puissance spécifiques de drainage à l'analyse d'un processus de drainage d'un échantillon de sol soumis à un degré constant de dépression (succion), on peut montrer qu'entre le débit spécifique de drainage Q'_{dr} (la quantité d'eau drainée du volume unitaire dans l'unité de temps: $Q'_{dr} = \frac{\gamma_s}{1+e} \cdot \frac{dw}{dt}$; γ_s — poids spécifique de la phase solide du sol; e — indice des vides) et la puissance spécifique de drainage il existe la relation

$$Q'_{dr} = \frac{\gamma_s}{1+e} \frac{\mathfrak{P}_{dr}}{s} = \frac{\mathfrak{P}'_{dr}}{s}. \tag{5}$$

De même, l'emploi de notions énergétiques permet la détermination des corrélations entre certains indices hydriques. Ainsi, la relation (1) montre que la succion représente la première dérivée du travail spécifique par rapport

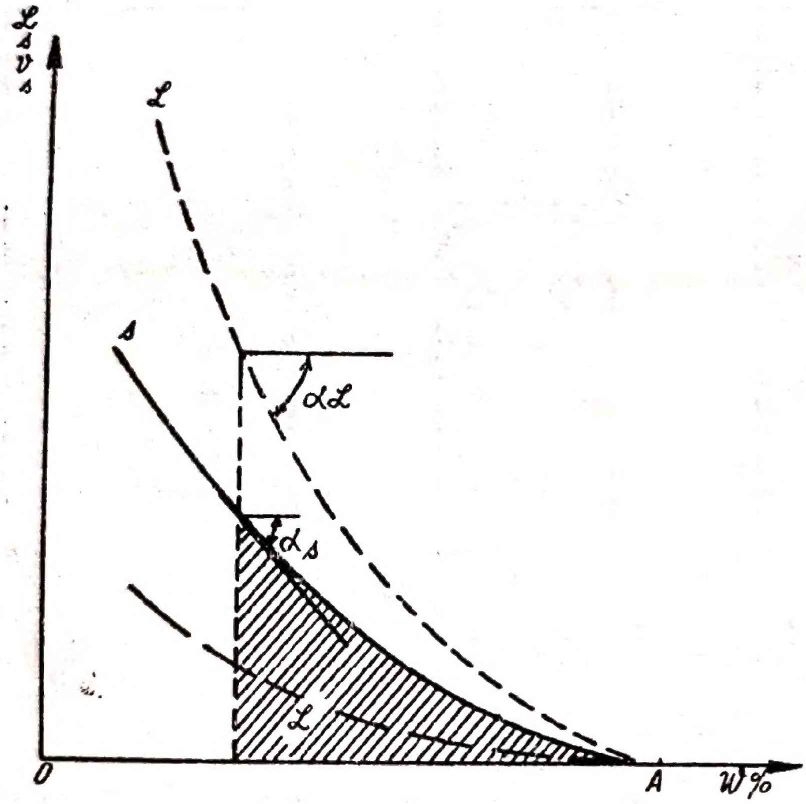

Fig. 3. Schéma montrant la corrélation entre le travail spécifique ($\mathfrak{L}$), la succion (s) et la variabilité de la succion (V_s).

à la teneur en eau. Si l'on dérive la succion par rapport à la teneur en eau, on obtiendra la variabilité de la succion (fig. 3):

$$V_s = \frac{ds}{dw} = \dot{s} = \ddot{\mathfrak{L}}. \tag{6}$$

Considérant la succion comme un potentiel négatif de transfert d'eau ($\theta = -s$), il résulte qu'entre la capacité hydrique spécifique $\left(c_w = \frac{dw}{d\theta}\right)$ et

a variabilité de la succion il existe la relation

$$V_s = -\frac{1}{c_w}. \tag{7}$$

Des courbes succion — teneur en eau établies expérimentalement (Andrei, 1963) on a pu déduire, à base de la relation (6), la variation du travail spécifique et de la variabilité de la succion avec la teneur en eau, résultant à la fois les ordres de grandeur de leurs valeurs maximales pour différents matériaux poreux:

— sable, craie .... $\mathfrak{L}_u \simeq 10^3$ gcm/g, $V_s \simeq 10^{10}$ gcm/g
— sable argileux, silts, loess, caolin, béton .... $\mathfrak{L}_u \simeq 10^4$ gcm/g, $V_s \simeq 10^9$ gcm/g
— argile active, papier-filtre, illite, asbociment .... $\mathfrak{L}_u \simeq 10^5$ gcm/g, $V_s \simeq 10^8$ gcm/g
— montmorillonite .... $\mathfrak{L}_u \simeq 10^6$ gcm/g, $V_s \simeq 10^7$ gcm/g.

On a pu évaluer aussi l'influence du degré de dispersion (fig. 4), de l'état de compacité et de la température sur le travail spécifique de drainage.

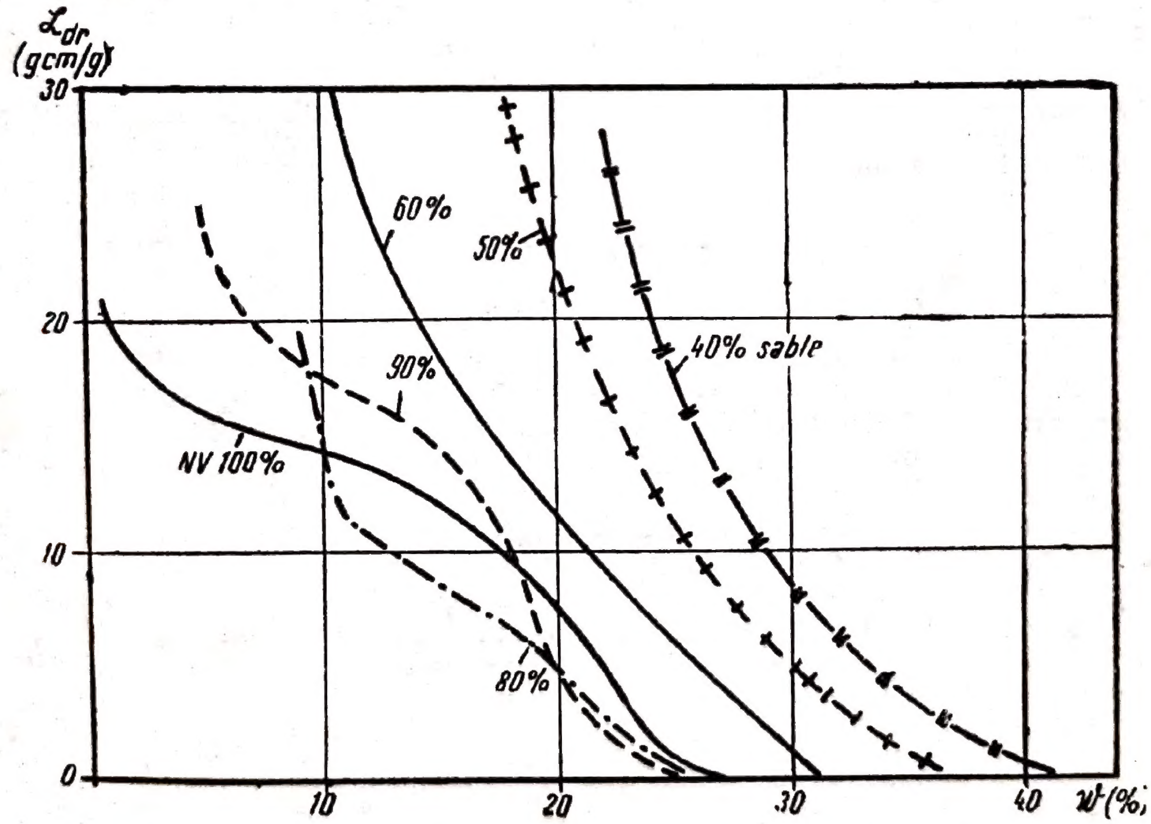

Fig. 4. Variation du travail spécifique de drainage dans le domaine pF = 0 — pF = 3 pour des mélanges en différentes proportions de sable fin de Văleni (*NV*; fraction 0,1—0,2 mm) et de loess de Bărboşi, fraction silt.

Cette dernière notion peut être appliquée aussi à l'évaluation des dépenses d'énergie liées à l'application des moyens de drainage d'intensités différentes :

— drainage simple, gravitationnel (pF $\simeq$ 2,5) .... $\mathfrak{L}_{dr} \simeq 10$—$20$ gcm/g
— filtres aciculaires vacuumés (pF $\simeq$ 2,8) .... $\mathfrak{L}_{dr} \simeq 35$—$55$ gcm/g
— drains d'aération (pF $\simeq$ 4,7).... $\mathfrak{L}_{dr} \simeq 10^2$—$10^3$ gcm/g
— séchage complet (pF $\simeq$ 7) :
  — sables fins .... $\mathfrak{L}_{dr} \simeq 10^4$ gcm/g
  — argiles actives.......... $\mathfrak{L}_{dr} \simeq 10^5$—$10^6$ gcm/g

Partant de l'équivalence entre l'énergie exprimée sous forme mécanique et calorique (1 cmg $= 2{,}34 \cdot 10^{-5}$ cal) et en admettant l'hypothèse qu'au cours du processus d'humectation toute l'énergie devenue disponible (le travail spécifique d'humectation $\mathfrak{L}_u$ en gcm/g) est cédée au milieu extérieur sous forme de chaleur (q_u en cal/g) il résulte la suivante relation de liaison :

$$q_u = 2{,}34 \cdot 10^{-5} \cdot \mathfrak{L}_u, \tag{8}$$

où

$$\mathfrak{L}_u = 4{,}24 \cdot 10^4\, q_u, \tag{8'}$$

d'où par dérivation, tenant compte de la relation (6), il résulte la relation entre la chaleur différentielle d'humectation $\left(q'_u = \dfrac{dq_u}{dw}\right)$ et la succion :

$$q'_u = 2{,}34 \cdot 10^{-5} \cdot s, \tag{9}$$

ou

$$s = 4{,}24 \cdot 10^4 \cdot q_u. \tag{9'}$$

A l'aide de cette relation, en se basant sur les données expérimentales concernant la chaleur différentielle d'humectation ($q'_u = 100 \ldots 600$ cal/g) (Doumanski, 1960), on peut montrer que pour l'état „séché à l'étuve" pF $= 6{,}63 \ldots 7{,}40$.

Toujours à base énergétique, on peut établir les relations existant entre les quatre modes suivants de caractériser l'interaction eau-phase solide (fig. 5) :

a) chaleur différentielle d'humectation — teneur en eau (q'_u, w) ;

b) humidité relative de l'air — teneur en eau (φ_w, w), c'est à dire les isothermes de sorbtion-désorbtion ;

c) succion — teneur en eau (s, w) ;

d) potentiel Luykov — teneur en eau (θ_L, w).

Pour faciliter l'étude des transferts de masse entre différents corps poreux, Luykov a proposé l'emploi du papier-filtre comme corps étalon et a défini comme potentiel d'humidité le rapport entre la teneur en eau (w) du papier filtre correspondant à un certain état d'équilibre de la teneur en eau,

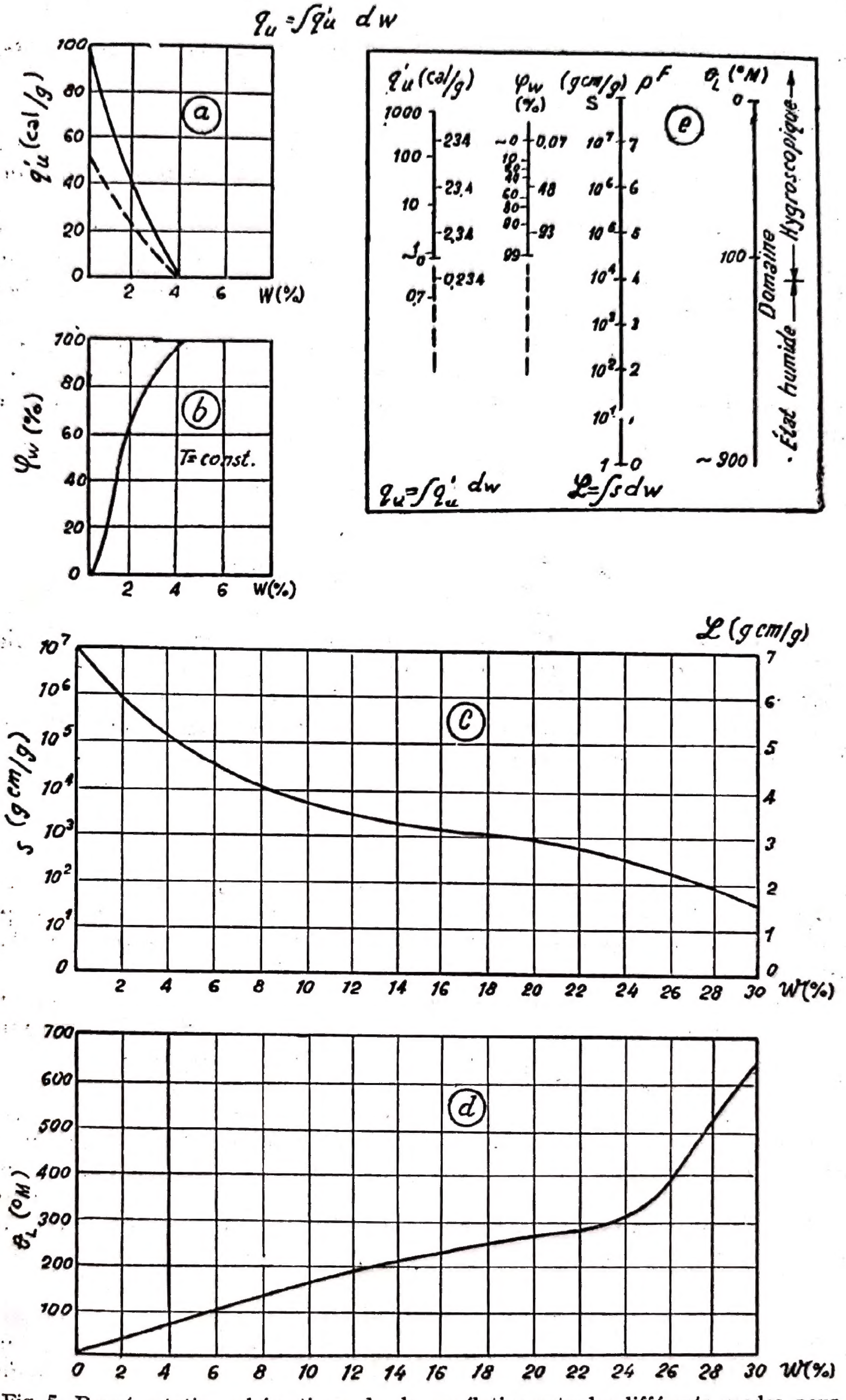

Fig. 5. Représentation schématique de la corrélation entre les différents modes pour caractériser l'interaction eau-phase solide des matériaux poreux : *a* — relation chaleur différentielle d'humectation-teneur en eau (q'_u, w) ; *b* — isothermes de sorption ou de désorption (φ_w, w) ; *c* — relation succion-teneur en eau (s, w) ; *d* — relation potentiel Luykov-teneur en eau (θ_L, w) ; *e* — correspondance entre les quatre échelles (q'_u, φ_w, s, θ_L).

et la teneur en eau du papier-filtre à hygroscopicité maximale (w_{HM}) : $\theta_L = \dfrac{w}{w_{HM}}$.

Ceci a son importance pour l'utilisation des données de la littérature concernant la caractérisation de l'interaction pour différents matériaux poreux.

La considération des transferts d'énergie qui surviennent au cours des processus de drainage-humectation s'est avérée utile pour l'étude des phénomènes liés à l'humectation des sols très secs, des loess en particulier (Andrei, 1962 ; Andrei, Culiţă, Sbenghe, 1962).

L'analyse du point de vue énergétique de l'autre aspect du processus de la circulation de l'eau à travers les sols, à savoir la filtration, a permis d'obtenir les expressions suivantes pour le travail et la puissance spécifique de filtration :

$$d\mathfrak{L}_f = \frac{\gamma_w}{\gamma_s}(1+e)\; k_w \cdot i^2 \cdot dt, \tag{10}$$

$$\mathfrak{Q}_f = \frac{d\mathfrak{L}f}{dt} = \frac{\gamma_w}{\gamma_s}\cdot(1+e)\cdot k_w \cdot i^2 \tag{10'}$$

où k_w est le coefficient de conductibilité hydrique et i le gradient hydraulique.

Prenant pour débit spécifique de filtration le poids de l'eau qui s'écoule en l'unité de temps par l'unité de surface perpendiculaire sur la ligne de courant, sous l'action d'un gradient constant ($Q_f' = \gamma_w \cdot k \cdot i$) et tenant compte de la relation (10) et de la figure 2, il résulte

$$Q_f' = \frac{e}{1+e}\,\frac{\mathfrak{Q}_f}{i} = \frac{\mathfrak{Q}_f'}{i}, \tag{11}$$

c'est à dire une relation similaire à la relation (5) obtenue pour le cas du drainage, d'où il apparaît que le gradient hydraulique représente, du point de vue énergétique, justement la puissance devant être dépensée pour la filtration de l'unité de poids du liquide en l'unité de temps.

Les notions énergétiques discutées auparavant prouvent leur application dans l'évaluation de l'effet retardant des forces de rétention dans le cas d'un processus de drainage, et de leur effet accélérant lorsqu'il s'agit du processus inverse d'humectation (Andrei, 1963).

Mais les processus du transfert de l'eau peuvent être provoqués non seulement en actionnant directement sur l'eau interstitielle, comme on vient de le montrer, mais aussi lorsque le sol est soumis à des sollicitations mécaniques provoquant sa déformation. En ce cas, une partie de l'énergie totale dépensée (W) est employée à la modification du volume (W_V), et l'autre partie, à la modification de la forme (W_{fm}), c'est à dire

$$W = W_V + W_{fm}. \tag{12}$$

Si nous nous limitons seulement à l'examen du processus de la modification du volume, tel qu'il a lieu dans l'édomètre ($W_{fm} \simeq 0$), où la défor-

mation latérale est empêchée, on pourra obtenir en considérant le prisme de sol saturé, en haut de la figure 6 a, qui, sous l'action de la pression p, modifie son volume de Δe, l'expression du travail méchanique total de compression, rapporté à l'unité de volume de la phase solide :

$$\Delta \mathfrak{L}_{cmp} = p \cdot \Delta e, \tag{13}$$

qui sera graphiquement représenté par le rectangle $AB'BC$ (au bas de la figure 6 a).

D'autre part, la théorie classique de la consolidation (Terzaghi, 1942) nous apprend que toute la pression appliquée est assumée dans le premier

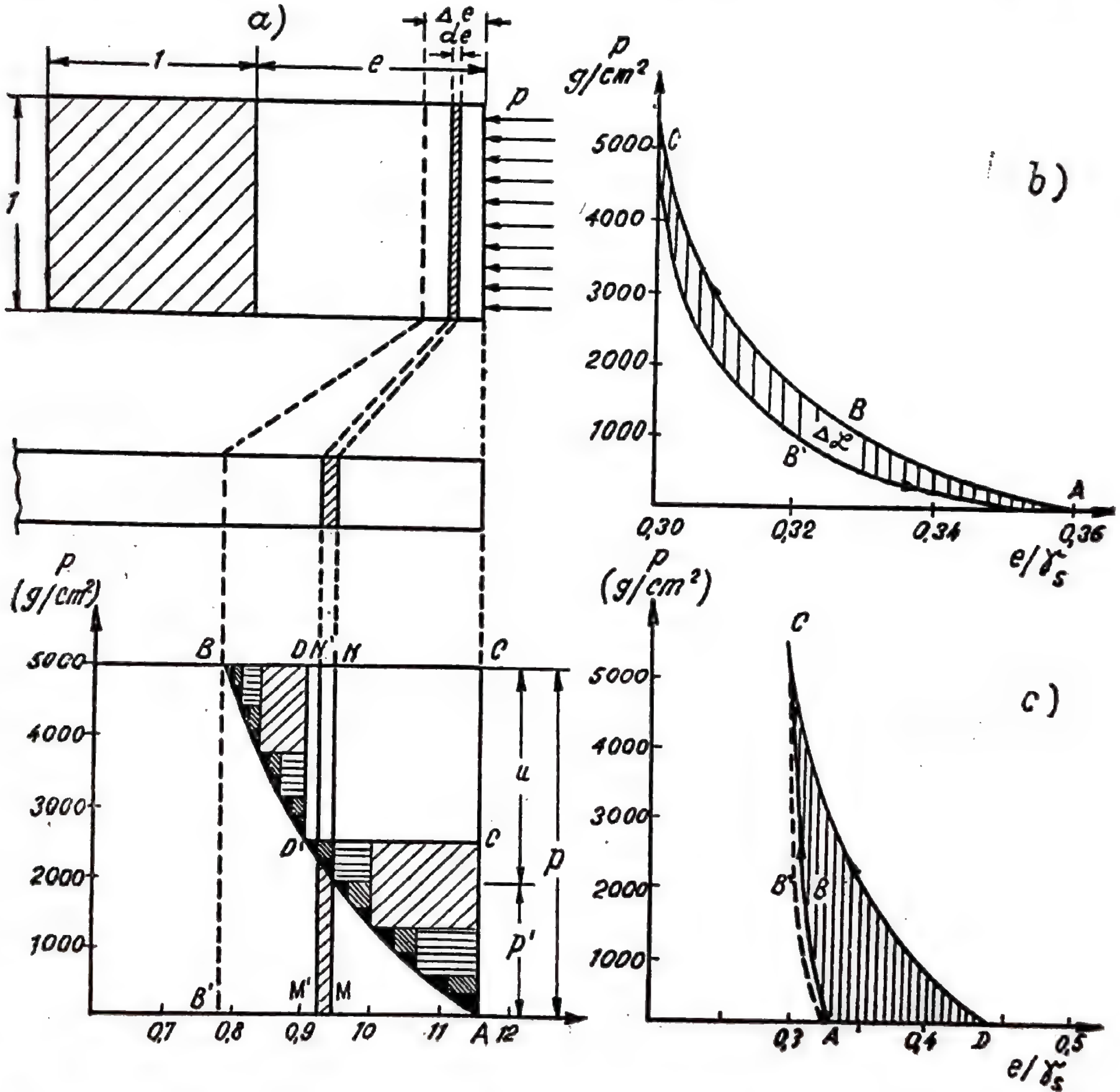

Fig. 6. Schéma pour la définition et l'interprétation graphique du travail spécifique de compression-gonflement : *a* — variation de l'indice des vides avec la pression et influence de la grandeur des degrés de pression sur le travail dépensé à l'évacuation de l'eau des pores ; *b* — boucle d'hystérésis formée par les branches de compression-gonflement ; *c* — représentation graphique du travail de compactage dans le cas d'une argile active.

moment par l'eau interstitielle passant ensuite, petit à petit, sur le phase solide ; donc, si l'on considère la courbe AB de variation de la pression effective p' assumée par la phase solide avec l'indice des vides (e), il sera facile à prévoir que le travail élémentaire utilisé au compactage de la phase solide sera

$$\mathrm{d}\mathfrak{L}_{cmp} = p' \cdot \mathrm{d}e, \tag{14}$$

représenté graphiquement par la partie hachurée du rectangle $MM'NN'$, qui se trouve sous la courbe (p', e).

En même temps, de la relation fondamentale établie par Terzaghi :

$$p = p' + u, \tag{15}$$

qui lie la pression totale appliquée (p) à la pression interstitielle (u) et la pression effective (p'), il résulte que la superficie $AD'BC$ située au-dessous de la courbe $AD'B$ représente justement l'énergie dépensée à l'évacuation de l'eau des pores au cours du processus de consolidation. Conformément à cette interprétation, plus les degrés des pressions appliquées seront bas, plus la partie de l'énergie totale utilisée effectivement au compactage de la phase solide sera haute, par rapport à celle employée à l'évacuation de l'eau des pores ; cette conclusion concorde d'ailleurs avec la relation (10), où l'on voit que le travail spécifique de filtration croît avec le carré du gradient hydraulique.

De la même manière que pour le processus de drainage, on peut montrer aussi que, dans le cas du processus de compression, la superficie de la boucle d'hystérésis $ABCB'$ (fig. 6 b) correspond à l'énergie dépensée irréversiblement pendant un processus se développant à une vitesse finie et que la superficie hachurée $ABCD$ de la figure 6 c représente l'énergie dépensée pour amener les particules existentes dans un état compact. De manière similaire on peut introduire les notions de puissance spécifique de compression-gonflement :

$$\mathfrak{Q}_{cmp} = \frac{\mathrm{d}\mathfrak{L}_{cmp}}{\mathrm{d}t} \tag{16}$$

et de variabilité de la pression

$$V_p = \frac{\mathrm{d}p}{\mathrm{d}e} = \dot{p} = \ddot{L}_{cmp} \tag{17}$$

et on peut montrer que la vitesse de réduction du volume du sol sous l'action d'une pression externe est proportionnelle à la puissance spécifique de compression (Andrei, 1963).

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RÉSUMÉ

Les phénomènes de drainage de l'eau des sols conduisant à l'apparition ou l'accentuation de l'état non saturé des sols et, par conséquent à la manifestation des forces d'interaction eau-phase solide, doivent être analysés non seulement du point de vue des transferts de masses, mais aussi du point de vue des transferts d'énergie. Pour en faciliter l'étude, il est recommandable de distinguer deux aspects : la filtration et le drainage-humectation. En effet, le processus de modification du volume d'un sol sous l'action d'une pression extérieure représente toujours un processus de drainage et de filtration.

La déduction et l'utilisation des expressions établies pour les transferts d'énergie qui accompagnent le développement de ces processus représentent non seulement un premier pas vers l'établissement de l'équation du bilan d'énergie, mais offrent en même temps la possibilité de comprendre plus profondément les phénomènes ayant lieu dans le système eau-phase solide, en partant de leurs éléments communs: les transferts de masse et d'énergie.

SUMMARY

The phenomena of soil water drainage, leading to the appearance or accentuation of the non-saturated state of soils and consequently to the manifestation of water — solid phase interaction forces, should be analysed not only from the point of view of mass transfer, but also from that of energy transfer. For study facilities, it is advisable to distinguish two aspects : filtration and drainage-humectation. Indeed, the process of volume modification of a soil under an external pressure action always represents a drainage and filtration process.

The deduction and utilisation of formulas expressing the energy transfer accompanying these processes, represent not only a first step towards developing an equation of the energy balance but allow at the same time a better understanding of the phenomena occurring in the system water-solid phase starting from their common elements : mass and energy transfers.

ZUSAMMENFASSUNG

Die Erscheinungen der Bodenwasserdränung, welche zum Auftreten oder zur Verstärkung des Unsättigungszustandes der Böden, folglich zur Äusserung der Wechselwirkungskräfte Wasser-feste Phasen führen, müssen nicht nur vom Gesichtspunkt der Massen, sondern auch von jenem der Energieübertragung verfolgt worden. Um ihr Studium zu erleichtern, empfiehlt es sich zwei Aspekte zu unterscheiden : die Filtration und die Befeuchtungsentwässerung. Tatsächlich stellt der Volumenveränderungsprozess eines Bodens unter dem Einfluss eines äusseren Druckes immer einen Dränungs- und Filtrationsprozess dar.

Die Ableitung und Anwendung der Ausdrücke, die für die Energieübertragungen festgesetzt wurden, welche die Entfaltung dieser Prozesse begleiten, stellen nicht nur einen ersten Schritt zur Festsetzung der Energiebilanzgleichung dar, sondern bieten zugleich die Möglichkeit eingehender die Erscheinungen zu verstehen, die im System Wasser-feste Phase stattfinden, ausgehend von ihren gemeinsamen Grundelementen: die Massen- und Energieübertragungen.

DISCUSSION

J. W. HOLMES (Australia). The quantity q_u given in Dr. Andrei's paper has the value of 100—600 cal/gm. Is this quantity related to the range of latent heat of water vaporisation in the range of free energy change in soils? Or what is its physical meaning?

S. ANDREI. Les valeurs $q'_u = 100$—600 cal/g représentent la chaleur différentielle d'humectation $\left(q'_u = \dfrac{dq_u}{d_w}\right)$ des différents matériaux poreux en dispersion et non pas la chaleur intégrale d'humectation q_u qui, pour le sol, est comprise entre 0 (sables) et 15—20 cal/g (argiles actives).

WATER RETENTION ABILITY AND MOISTURE TENSION (pF) OCCURRING AT FIELD WATER CAPACITY IN ARTIFICIAL HOMOGENEOUS PROFILES OF SEVERAL POLISH SOILS

MIECZYSLAW BIRECKI, STANISLAW TRZECKI [1]

1. INTRODUCTION AND REVIEW OF LITERATURE

When determining the field water capacity of some soils in the 1961 and 1962, field conditions and comparing the results obtained with those calculated from moisture tension determinations in samples of the same soils in the laboratory, a wide divergence was found in the results (Birecki and Trzecki, under print). In the literature available at that time, field water capacity was reported to occur at a moisture tension of about 1/3 atm, which strictly corresponds to a water head of 345 cm, i.e. to a pF value of 2.54 (Piper, 1957; Richard and Beda, 1953). In view of elucidating these controversial results, investigations in greater detail were undertaken which, to achieve high precision and reproduction possibilities of results, were carried out on artificial homogeneous soil profiles. It became known only later that other authors dealing with this problem also found experimentally that the field capacity of soils occurs at a much lower moisture tension of about pF=2 (Peerlkamp and Boekel, 1960).

Research on soil water characteristics — a complex and variable factor — has been also undertaken by means of theoretical considerations and verification experiments (Childs and Poulavassilis, 1952).

As regards water retention in the soil profile, theoretical calculations and their experimental corroboration were given by Childs and Poulavassilis (1962). In order to confirm the correctness of the theoretical premisses, porous substances of accurately known capillary size were used (Waldron et al., 1961). In the same year Panfilov (1962) publishing his data of the optimum moisture conditions for wheat production, claimed that, 10 days after soil saturation with water (at what he called moisture of capillary chain rupture) moisture stabilizes in the soil profile, changing no more in the next 10—20 days. In the present investigations, the results of which are reported below, the longest period at the end of which the water retained in the profile was determined, was 10 days.

[1] Warsaw Agricultural University, PO ISH PEOPLE'S REPUBLIC.

2. AUTHORS' OWN INVESTIGATIONS

The studies were performed in the period 1962—1963 in the Department of General Soil and Plant Cultivation, Warsaw Agricultural University, on soils from the Experimental Agricultural Station at Chylice. The following four soils were investigated:

1) arable layer of black soil;
2) light loam underlying the black soil;
3) light sandy-loam from the arable layer of podsol;
4) loose sand on sandy-loamy subsoil.

After sieving the soil through a 2 mm mesh and a thorough mixing, a homogeneous material was obtained from which artificial profiles 140 cm high were prepared in plexiglass tubes. Care was taken to maintain, as far as possible, a uniform texture of the entire profile. For each soil 3—4 replicates of the profile were made. The soil in the profiles was saturated with water for 2—3 days by means of a dosing device, so that water should not stay on the profile surface. This procedure allowed to saturate the whole profile accurately, and at the same time prevented air bubbles from remaining in the pores. The water permeating, partly or entirely, through the profiles, was drained off at the bottom. After saturating the profiles, the surface was protected from evaporation, and the profiles were left to stand for a definite period to let the free water drain off.

In one group of experiments, a water table was maintained at a depth of 140 cm in the profiles, and 2, 3 and 4 days were assumed as a time sufficient for draining the excess water.

In the second group of experiments, instead of the water table, a metal mesh constituted the bottom of the profile. For draining of the excess water, the profiles were left to stand for 3—10 days, then they were divided into 10 cm layers and in each of these the water content and the specific volume weight of the soil were determined.

Parallelly the soil moisture tension (pF) was determined in soils with a texture similar to that in the respective profiles at pressures of 0.01; 0.03; 0.1; 0.3; 1; 2; 10 and 16 atm. Some physical and chemical properties of the soils used for the artificial profiles, which might influence the moisture conditions, were also determined: specific weight (pycnometrically), index of water permeability (according to Polish Standard, PN-55/B-04492), percentual content of humus (Tiurin's method), and mechanical analysis (Bouyoucos' method in Casagrande's and Prószyński's modification).

The results of these determinations are compiled in tables 1 and 2.

It is seen from the data in these tables that the soils used for the artificial profiles differ widely from one another. These different types of soil were selected purposely in order to study on them the problem of water retention and the moisture tension in the profile at water field capacity (after 3 days) and somewhat later (10 days).

Table 1

Some Phisical and Chemical Properties of the Soils Under Investigation

Soil	Specific weight	Index of permeability to water in cu. cm /min in conditions of the profile	Index of permeability to water in cu. cm/min with load of 0.4 kg/sq.cm	Humus per cent
1. Black soil	2.61	0.160	0.015	1.70
2. Light loam	2.63	0.046	0.006	0.26
3. Light sandy-loam	2.65	0.240	0.048	0.80
4. Loose sand	2.68	0.660	0.255	0.07

Table 2

Mechanical Analysis of Soils Under Investigation

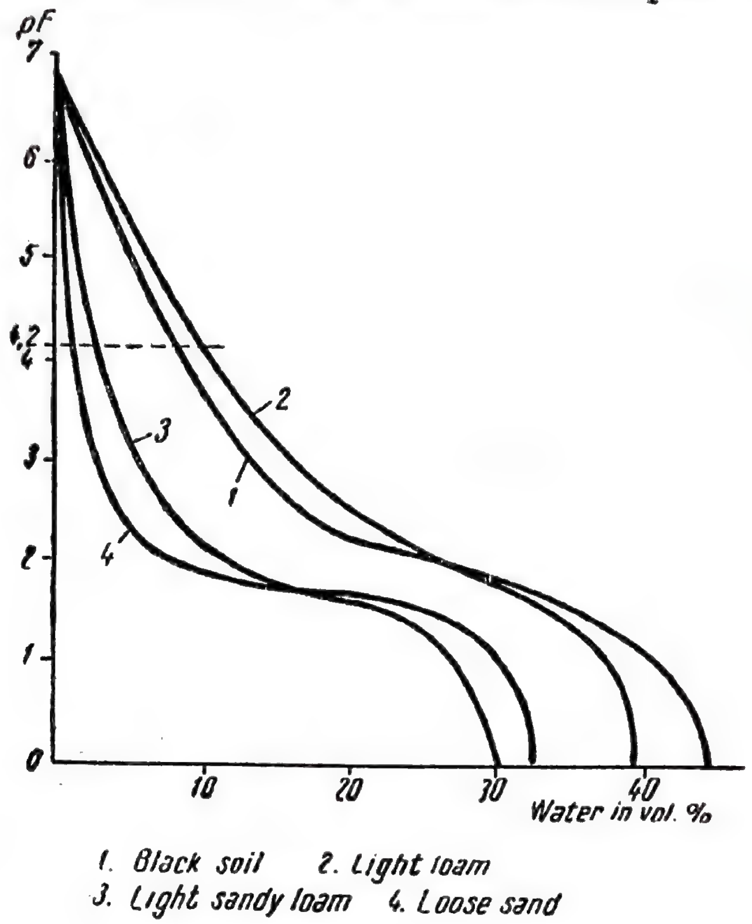
Soil	Skeletal parts per cent	Soil fractions per cent	Percentual content of soil fractions (diameter in mm)								Total percentage of soil fractions (diameter in mm)		
			1—0.5	0.5—0.25	0.25—0.1	0.1—0.05	0.05—0.02	0.02—0.006	0.006—0.002	< 0.002	1—0.1	0.1—0.02	< 0.02
1. Black soil	2.7	97.3	13.7	21.6	24.2	7.5	8.5	8.0	4.5	12.0	59.5	16.0	24.5
2. Light loam	3.9	96.0	10.0	21.4	25.1	10.5	7.5	7.0	4.5	14.0	56.5	18.0	25.5
3. Light sandy-loam	1.1	98.8	17.7	26.3	34.0	10.0	3.5	2.5	3.5	2.5	78.0	13.5	8.5
4. Loose sand	1.5	98.5	19.3	32.6	37.1	5.5	1.0	1.0	2.0	1.5	89.0	6.5	4.5

The retention forces in the particular soils (artificial profiles) were determined in laboratory conditions on ceramic plates and membranes The results of the determinations are represented by the pF curves in figure 1.

As seen from the figure, there are rather wide differences in the water-retention ability between the particular soils. Loose sand retained the smallest amount of water (both available and unavailable), light sandy-loam had a somewhat higher retention ability, whereas black soil and light loam exhibited a much higher content of retained water. As regards the last named two types of soil, black soil retained more water, up to pF=2, and above this value the reverse occured.

The moisture relationships in the artificial profiles of the soils under study formed at various time periods after saturation with water, and depending on the presence or absence of a water table, are illustrated in figure 2. This figure shows the percentage in volume of unavailable water to plants in the 10 cm layers of the profile, the total amount of water retained at various

times after saturation (including field capacity), the capillary and total capacity, the contribution of the solid phase and the moisture tension expressed as a pF value at various periods after the saturation of the profile.



Soil	Capillary porosity			non capillary porosity	total porosity
	large pores>10μ	medium pores 10–0,2μ	small pores<0,2μ		
1. Black soil	27.2	8.8	8.5	6.5	51
2. Light loam	18.7	10.6	9.7	12.0	51
3. Light sandy loam	21.7	8.0	3.3	7.0	40
4. Loose sand	22.3	6.2	1.5	7.0	37

Fig. 1. pF Curves and Porosity of The Four Soils Studied.

From the graphically presented data (fig. 2) it results that the soil material had, at various depths, an uniform texture. The contribution of the solid phase in black soil was 49, in light loam 49, in light sandy-loam 60 and in loose sand 63 per cent. However, the ratio of capillary to noncapillary porosity was somewhat changed. In the lower layer of the profile, as seems

to result from the figure, capillary porosity increased at the cost of non-capillary porosity. This was most probably caused by a partial shift of soil particles during filtration after saturation of the profile with water, and/or by a re-orientation of soil particles which did not result in any corresponding change in the specific volume weight of the soil.

The soils differed widely in the quantity of water retained (available and unavailable). If the particular soils are considered, the conclusion may on advanced that, depending on the time elapsed after saturation and on the presence or absence of the water table, wider differences occurred in heavier soils than in light ones.

The moisture pattern at various depths of the profile was also characteristic. Depending on the type of soil it slightly increased to a depth of 60—90 cm, whereas in the deeper layers it rose steeply reaching at the water table the full capillary capacity. The fact that the absence of the water table and a longer time period elapsing after complete saturation did not radically change these conditions may be ascribed to the water-holding forces in the profile. These forces seem to be stronger in the deeper soil layers (below 70—90 cm), since the quantity of water retained here is greater. It is possible that this is caused by a lack of direct connection between the larger capillaries (over 8 μ in diameter), and, consequently, to the occurrence of additional tension (moisture tension) due to the water bound by stronger forces in the medium capillaries (8—0.2 μ) which interconnect the large ones.

This phenomenon also allows the supposition that the presence of a temporary water table in the soil should be ascribed not only to the impermeability of the substrate but also to the retention forces in the deeper soil layers in which, as the present studies seem to indicate, even as late as after 10 days the content of water retained in the layers below 120—130 cm was close to capillary capacity (even in profiles without water table and in a soil with a relatively loose texture). The confirmation of this hypothesis requires, however further investigation.

The second object of the investigations performed on the artificial profiles was to establish to what pF values „field water capacity" corresponds, and what are the relations governing this problem not only in surface but in deeper situated layers. The pF value most frequently reported in literature is 2.54 (Thomas and Moody, 1962; Waldron et al., 1961), though some authors characterise also the soil water properties at pF = 2 (Kuipers, 1961 a, 1961 b).

The field capacity measurements made by us in field conditions differed widely from this value. Soil moisture at field capacity was higher than that at pF = 2.54 indicating that either the subsoil must be impermeable or else the calculated value is too high.

This was confirmed by the determinations carried out in the artificial profiles (fig. 2), from which it resulted that at "field capacity" the pF value is lower, and that it is not a constant value. Namely, depending on soil type and the presence or absence of the water table, the following values were obtained for the pF value in the upper layers of the profile:

— after 3 days in profiles with water table at a 140 cm depth: 2.0—2.2,

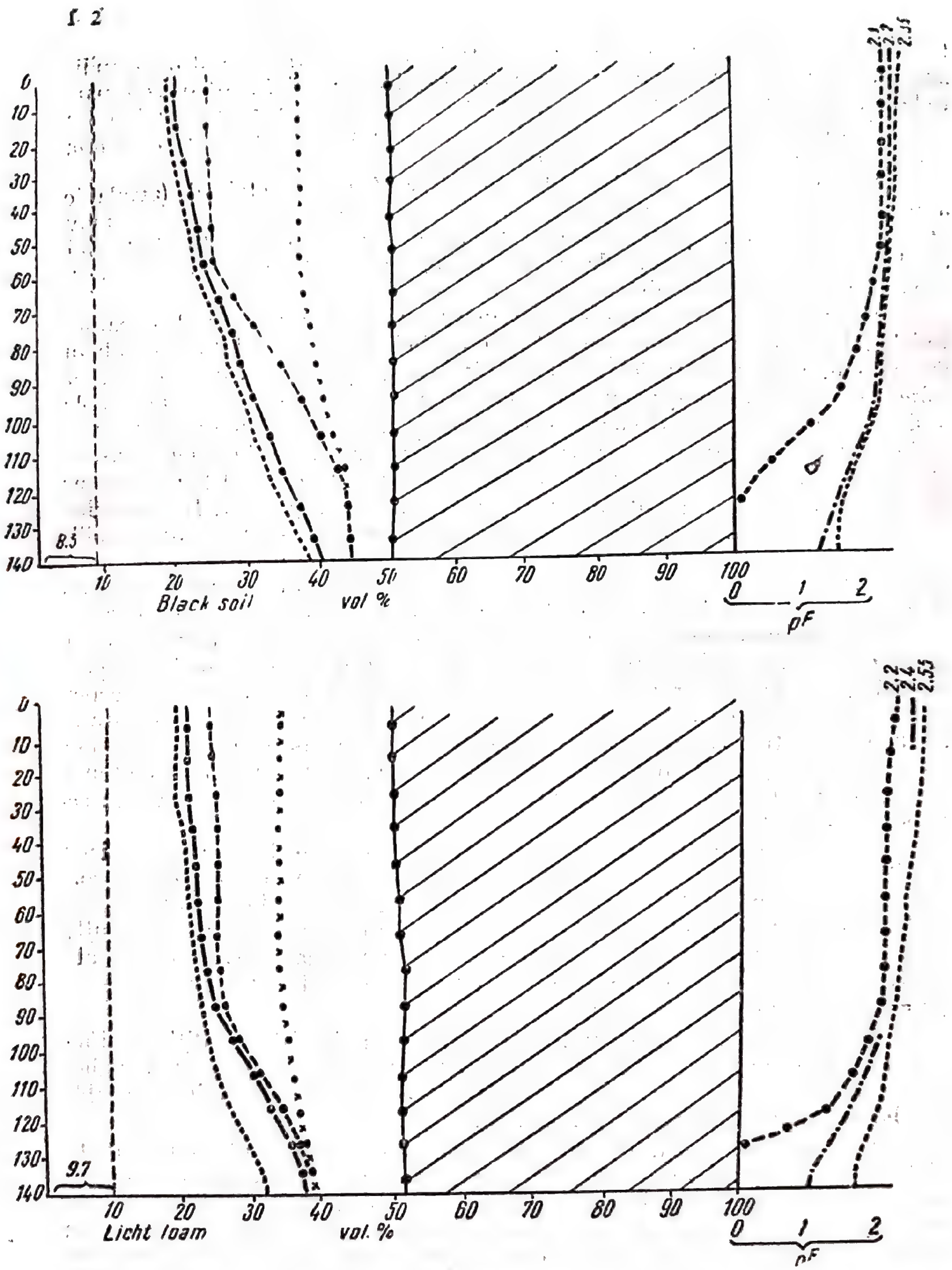
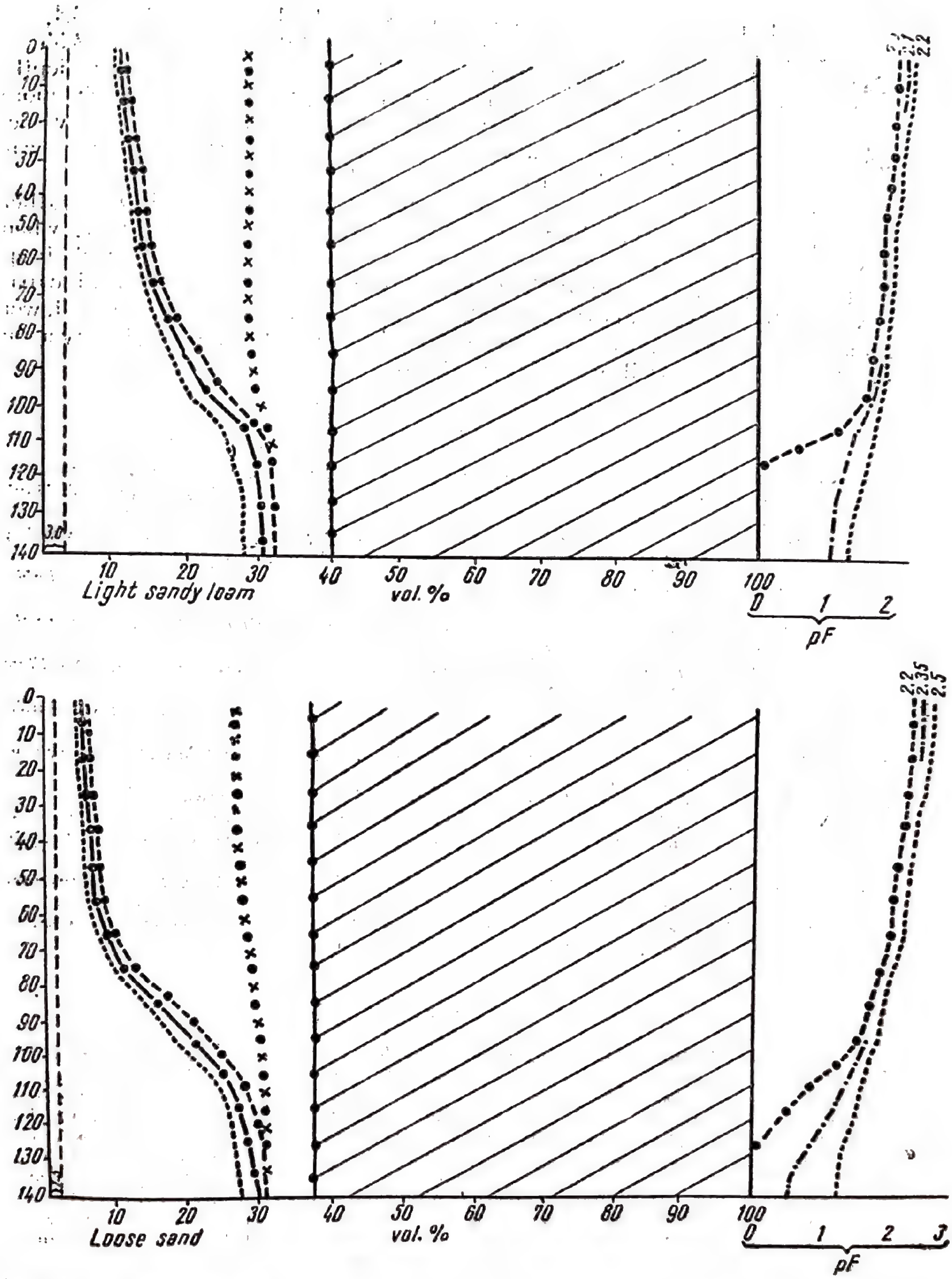


Fig. 2. Moisture Relations

— — — nonavailable water; ——— water retained after 10 days in profile without profile without water table, expressed in vol. % and as pF values; —·—·— water vol. % and as pF values; .x.x. capillary porosity: —·—·—

L 2



in The Four Soils Studied.

water table, expressed in vol. % and as pF values; —·—·— water retained after 3 days in retained after 3 days in profile with water table at a depth of 140 cm, expressed in total porosity; hatched part: constant soil phase.

— after 3 days in profiles without water table: 2.1 — 2.4,
— after 10 days in profiles without water table: 2.2 — 2.55.

The pF value characterizing the retained water decreased with depth, at first slightly up to 70—90 cm and than with depth increasing much more rapidly reaching, after 3 days in profiles with a water table, a zero value, whereas in those where the water table was absent the pF value was 0.5—1.2. Even after 10 days its value was still 1.15 to 1.7.

It should be stressed that, in artificial profiles, the soil was rather loose and easily permeable to water. It is therefore probable that, when the soil is more compact and permeability reduced, as is most frequently the case in a natural field profile, the water content at field capacity may be higher, thus the pF value lower both in the upper and lower layers of the profile. This of course does not refer to the arable layer in which structure as well as water conditions are more changeable.

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SUMMARY

For the investigations carried out in 1961—1963 four different soils were used, from which 140 cm high soil profiles were prepared, consisting of homogeneous material. The profiles were then saturated with water, protected from surface evaporation and left for a more or less long period (2—10 days) to allow excess water to drain off. In some of the profiles a water table was being kept up, in others it was not. After a certain time, the quantity of retained water was determined at various depths in the profile. It was established that the moisture tension in the upper soil layers at field capacity was smaller than the pF = 2.54 generally mentioned in literature. Data obtained from our researches show that in permeable soils with a water table at 140 cm. depth, the pF values of the field capacity are 2.0—2.2, whereas in those without water table, they are 2.1—2.4. Only after 10 days did the pF values vary, in profiles without water table, from 2.2 to 2.55.

RÉSUMÉ

Pour les essais réalisés en 1961—1963, on a utilisé des profils artificiels homogènes de 140 cm. d'épaisseur, composés de matériaux provenant de 4 sols différents. Les profils, saturés d'eau, protégés contre l'évaporation superficielle, ont été laissés reposer de 2 à 10 jours, afin de permettre l'écoulement du surplus d'eau. Dans certains profils on a maintenu une nappe d'eau , mais pas dans d'autres. Après un certain temps on a déterminé la quantité d'eau retenue à différentes profondeurs dans le profil. On a constaté que les forces de rétention pour l'eau dans les couches superficielles du sol n'atteignaient pas la valeur pF = 2,54, citée en général dans la littérature. Nos essais démontrent que la valeur du pF varie de 2,0 à 2,2 pour les sols perméables ayant la nappe d'eau à une profondeur de 140 cm, tandis que pour les mêmes sols, sans nappe d'eau, cette valeur varie de 2,1 à 2,4. On a constaté chez ces derniers sols, que seulement après 10 jours les valeurs du pF variaient de 2,2 à 2,55.

ZUSAMMENFASSUNG

Zu den 1961 — 1963 durchgeführten Untersuchungen wurden 4 verschiedene Böden herangezogen, aus welchen man künstliche, 140 cm hohe, und aus einheitlichem Material gebildete Bodenprofile hergestellt hatte. Die Profile wurden mit Wasser gesättigt, von oberflächlicher Verdunstung geschützt und zur Absickerung des überschüssigen Wassers für verschiedene Zeitdauer (2—10 Tage) abgestellt. In einem Teil der Bodenprofile wurde der Wasserspiegel erhalten ; im anderen dagegen nicht. Nach einer gewissen Zeit wurde die Menge des in verschiedenen Tiefen der Bodenprofile erhaltenen Wassers bestimmt. Es wurde festgestellt, dass die Saugkräfte der oberen Bodenschichten bei der Feldkapazität kleiner sind als der im allgemeinen in der Literatur angegebene pF-Wert = 2,54. Aus unseren Untersuchungen ergibt sich, dass in durchlässigen Böden, mit Wasserspiegel in 140 cm Tiefe, die pF-Werte der Feldkapazität bei 2,0—2,2 und ohne Wasserspiegel bei 2,1—2,4 liegen. In Bodenprofilen ohne Wasserspiegel lagen die pF-Werte, erst nach 10 Tagen, zwischen 2,2—2,55.

THE pF CURVES AND THEIR RELATION TO THE BASIC WATER CONSTANTS IN CHERNOZEM SOILS IN THE IRRIGATED AREA OF BACKA [1]

NOVICA VUČIĆ [2]

The irrigation area in Backa covers about 70 per cent of the watering areas (350,000 ha) of the Danube-Tissa-Danube hydrosystem, which is under construction. The soil cover of this area is mainly chernozem — over 90 per cent — with its subtypes and varieties, and therefore the knowledge of its water properties must be the basis of rational irrigation of practically the whole irrigation area in Backa (Vučić, 1962).

Owing to the fact that the pF curves reveal the mutual relationships in the soil-water-plant system more clearly than the other methods hitherto applied do these curves play a particular role and have a special importance in irrigation.

Certain authors are of the opinion that the pF curves of the soil cannot serve as a reliable basis for an indirect computation of the values of field water capacity and of wilting moisture. However, if we take into account the fact that field water capacity and wilting moisture are affected by several factors and that their values, according to recent views, represent an interval of moisture, not a point, the pF values should also be regarded more realistically. This is suggested by the fact that all authors agree with the conclusion that the pF values 2.5—2.7 and 4.2 represent the average respective values of field water capacity and of wilting moisture.

THE pF CURVES AND THE BASIC WATER CONSTANTS OF CHERNOZEM

The pF curves have been obtained after the procedure recommended by Marshall (1959), while the field water capacity and wilting moisture have been determined by standard methods (Astapov, 1958; Kramer, 1949).

The average pF value corresponding to the field water capacity is pF 2.5, though there is a wide range of variations; still, the values largely

[1] Backa is a part of Voivodina, a large plain in the Pannonian basin in the north of Yugoslavia.

[2] Faculty of Agriculture, Novi Sad, SOCIALIST FEDERATIVE REPUBLIC OF YUGOSLAVIA.

Table 1

Basic Water Constants (Percentage of Weight) and Their pF Values

Soil horizons	Field water capacity	Moisture equivalent	"½ atm.percent." (samples in a disturbed state)	Initial wilting moisture	Permanent wilting moisture	"15 atm. percent."	Lentocapillary moisture	pF values: Field water capacity	pF values: Permanent wilting
				Calcareous Chernozem of the loess terraces					
A-ar.	25.7	24.5	25.2	14.4	10.9	11.8	15.6	2.95	4.25
A-subar.	26.2	26.4	25.8	15.0	11.2	14.3	16.8	2.20	4.40
AC	24.8	28.1	27.6	14.0	11.4	14.1	17.8	2.65	4.40
C	23.1	23.3	27.0	12.0	8.8	8.9	12.0	1.90	4.20
				Limeless Chernozem of the loess terraces					
A-ar.	25.4	—	27.6	14.5	12.1	15.0	17.5	2.90	4.45
A-subar.	26.4	—	27.7	16.0	12.8	17.0	17.1	2.40	4.50
AC	24.4	—	25.9	13.3	12.6	14.2	16.1	2.10	4.35
C	23.0	—	24.1	11.9	10.7	11.6	14.4	2.22	4.25
				Calcareous Chernozem of the loess plateaus					
A-ar.	24.8	24.5	24.8	10.8	9.2	11.5	14.1	2.50	4.40
A-subar.	24.8	24.6	25.7	11.7	10.3	12.5	14.8	2.65	4.40
AC	23.5	24.7	25.4	11.7	9.6	12.3	15.3	2.75	4.55
C	22.1	21.0	21.2	8.8	7.1	7.3	10.4	2.60	4.20
				Chernozemlike Meadow soil (calcareous)					
A-ar.	26.7	24.5	25.5	13.8	11.3	13.1	16.1	2.80	4.30
A-subar.	26.6	26.6	26.6	13.9	11.5	15.3	17.9	2.25	4.45
AC	25.8	28.2	27.9	12.7	10.9	14.3	17.3	2.70	4.45
CG	23.7	23.2	26.3	9.8	8.4	7.8	11.0	2.40	4.10

vary within the 2.5—2.7 pF values (in undisturbed soil samples). In the case of samples in a disturbed state the values of "$^1/_2$ atm percentage" (pF = 2.7) approach more the field water capacity, particularly in the A horizon. In these soils the moisture equivalent is even closer to the field water capacity, and although a correlation exists with the "$^1/_2$ atm percentage", there are deviations, especially in the *C* horizon.

An analysis of the pF values of the moisture of permanent wilting reveals a differentiation of values at different depths of the soil profile. In the *A* and *AC* horizons the pF values of the wilting moisture are higher — amounting to about 4.4, while in the *G* and *CG* horizon, they amount to 4.2. Expressed as pressure, these values have a range of 15—25 atm. Richards and Weaver (quoted in Baver, 1956) have found that sunflower begins to wilt at a moisture content corresponding to a pressure of 5—13 atm, while permanent wilting sets in within the range of 20—40 atm. This means that the pF value 4.2 or „15 atm percentage" corresponds more closely to the initial wilting moisture, and agrees with the present author's findings in table 1 concerning the *A* and *AC* horizon, whereas in the *C* and *CG* horizon it is nearer to the moisture of permanent wilting.

The "lentocapillary moisture", determined under a pressure of 6.25 atm by means of the pressure membrane apparatus, corresponds to the „capillary connection break moisture" of Soviet authors (Abramova, quoted in Rode, 1955), as it lies mainly within the range of 60—70 per cent of the field water capacity and may be utilized in irrigation as the lower limit of optimum moisture. Deviations are mainly found in the *C* horizon, at a depth of over 100 cm, beyond the limits of the active rhizosphera, and are consequently of no particular interest from the point of view of irrigation.

CONCLUSION

In the chernozem soil examined, the moisture levels at pF = 2.7 and pF = 4.2 may be used for practical purposes, as their respective values approach those of the field water capacity and the initial wilting moisture.

The lentocapillary moisture — pF = 3.8, taken as the lower limit of optimum moisture content, is in agreement with modern views on the subject.

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SUMMARY

From the results obtained it was concluded that the pF curves provide applicable values in iriigation practice on the chernozems of Vojvodina.

pF values at field capacity vary to a great extent at different depths of the profile, but the values are mostly in the range of 2.5 (undisturbed samples) to 2.7 (disturbed samples).

The moisture equivalent is even more similar to the field capacity.

15 atm percentage (pF = 4.2) corresponds better to the first permanent wilting point for the *A* and *AC* horizons .

Lentocapillary moisture coincides with the moisture of the capillary connection rupture of soviet authors.

RÉSUMÉ

Dans la pratique, les courbes du pF dans le chernozem de la Vojvodina (Yougoslavie) donnent des valeurs utilisables pour l'irrigation.

Les valeurs du pF à la capacité au champ varient avec la profondeur du profil entre des limites assez larges, mais se trouvent pour la plupart situées entre les valeurs de 2,5 (pour les échantillons non dérangés) et 2,7 (pour les échantillons; dérangés.

L'humidité équivalente est encore plus proche de la capacité au champ.

Le pourcentage à 15 atm (pF=4,2) correspond plutôt à l'humidité au début du point de flétrissement pour les horizons *A* et *AC*.

L'humidité de capillarité ralentie correspond à l'humidité d'interruption des liaisons capillaires des auteurs soviétiques.

ZUSAMMENFASSUNG

Für praktische Zwecke stellen die pF-Kurven des Tschernosems der Vojvodina (Jugoslawien) brauchbare Werte dar.

Die pF-Werte der Feldkapazität variieren beim Tschernosem mit der Profiltiefe zwischen ziemlich weiten Grenzen, sie liegen aber trotzdem hauptsächlich innerhalb 2,5 (für Proben in unverändertem Zustand) und 2,7 (für Proben in verändertem Zustand).

Der Feuchtigkeitsäquivalent ist noch näher der Feldkapazität.

Der Feuchtigkeitswert bei 15 Atmosphären-Saugspannung entspricht mehr der Anfangsfeuchtigkeit des Welkepunktes für den *A*- und *AC*-Horizont.

Der "Lentokapillarpunkt" entspricht dem von den Sowjetautoren als Kapilarrißpunkt bezeichneten Begriff.

DISCUSSION

A. A. RODE (U.S.S.R.). In many articles we can see attempts to determine a common suction value for all soils (and moisture potential) for the moisture content which equals the field capacity. It seems to me that such attempts are not successful. Let us consider a solum thoroughly moistened down to the depth of the ground water table with the cappilary fringe forming above it. Suction at the upper boundary of the fringe expressed in cm of water, equals the thickness of the capillary fringe expressed also in cm. The upper boundary of the capillary fringe coincides with the lower boundary of the upper layer thoroughout which the moisture content is constant in the whole of this layer and equals the field capacity. Subsequently the suction, which equals (in cm) the thickness the capillary fringe, corresponds to the moisture content at field capacity. The thickness of the capillary fringe varies greatly in different soils, from 30—40 cm in sands up to 3—4 m in heavy silty loam. Therefore the suction value corresponding to field capacity differs from 30 — 40 cm up to 300 — 400 cm of water.

D. HILLEL (Israel). It appears futile to seek a point on the pF (or "soil moisture characteristic") curve to correspond with "field capacity". The pF curve represents equilibrium states and it shows no discontinuities. "Field capacity" as commonly defined is not an equilibrium point at all but as an empirical value measured at an arbitrary time during a continuing process of soil-water redistribution following infiltration. As such, "field capacity" depends upon the profile boundary conditions. Though sometimes useful, it is a theoretically ill-defined concept and may at other times be misleading. The explanation for "field capacity" in any case, can better be found in the hydraulic conductivity vs. moisture content curve, rather than in the pF curve. The hydraulic conductivity curve, while also continuous, drops to relatively low values at lower moisture contents so that in a deeply wetted soil (where mean suction gradients are low and gravity is the principal moving force) after a few days the moisture content changes very slowly. But when does the change become so slow that we can disregard it and assume that the soil moisture remains constant? That is arbitrary.

S. A. TAYLOR (U.S.A.). The permanent wilting point, like field capacity, is a dynamic value that depends on both the potential of water in the soil and the rate of removal. The removal rate in turn depends upon the atmospheric demand and the proportion of roots in a given volume of soil. It is likely that root distributions are different in the various horizons. Hence the reported differences may be a consequence of the method of measurement.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 4

SUCTION CHANGES DURING THE PROCESS OF SUSPENDED MOISTURE EVAPORATION

A. A. RODE, G. I. ROMANOVA[1]

It has been established by Rode (1947) and Bolshakoff (1950) that the suspended moisture is moving in liquid state upwards to the evaporation surface. Abramova (1953) made a careful, close study of this phenomenon under laboratory experimental conditions. This study resulted in the concept of "moisture of the capillary connection rupture" as the minimum value of soil moisture at which the ascending movement of moisture ceases.

Suspended moisture moves upwards during the process of evaporation. It could be assumed that the motive power of this phenomenon is suction which is peculiar to soils unsaturated with water. However, it could be objected that ascending movement of suspended moisture, especially at its first stages, is going on without moisture gradient (in case the texture and packing are uniform along the solum) which is usually considered to be connected with suction gradient. Furthermore Abramova's (1953) and Hallaire and Henin's (1958) data prove that suspended moisture is able to move even towards wetter layers. But with the moisture content increase, suction increases. It should be noted that we deal with an algebraic magnitude of suction which is negative in soils unsaturated with water.

It seems that suspended moisture, as it is proved by Abramova's, and Hallaire and Henin's data, is moving during the evaporation with zero suction gradient or even in the direction of this gradient; it is known, however, that moisture may move opposite this gradients, i.e. from wetter layers (with higher suction) to the dryer layers (with lower suction).

How can this contradiction be explained? An experiment was made to find out how the suction changes during the evaporation of suspended moisture and how suction change is connected with the change of soil moisture content.

A box of galvanized iron, 60 cm high, 60 cm long and 20 cm wide, was filled with the same loam that had been used in Abramova's experiment. Some holes were made in the box sides. Through these holes the tensiometers

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cups with Hg-manometers were inserted as far as 5, 8, 12, 16, 21, and 26 cm from the surface. The loam was moistened but not to the bottom, to determine suspended moisture. After the infiltration was completed, the surface of the loam was carefully protected from evaporation. The surface was opened 5 days later in the first experiment and 13 days in the second one. To accelerate the evaporation process three lamps 40 wt/each were placed above the loam to warm slightly the surface. The heating went on for 6 hours daily. Tensiometer readings were taken daily at 9 o'clock before the lamps were switched on. The moisture content was determined by boring in four replicates at intervals of 1—4 days in the layers at 0—2.5, 2.5—5, 5—7.5, 7.5—10 cm and at every 5 cm deeper layer. The loam bulk density equaled to 1.55 g/cm^3.

The results of the experiments are shown in fig. 1 A and B. On each of them there are moisture distribution profiles given as percentages of the loam weight (the right group of continuous lines) and corresponding to them suction profiles given in mm. of Hg (the left group of dotted lines). The moisture and suction magnitudes are increasing (suction is increasing algebraically) from left to right. The numbers near the curves show the number of days from the beginning of evaporation. The day when the surface was opened is taken as zero. On these figures only some of the curves are shown, as related to the most typical moments.

In figure 1A is shown that at zero time the moisture content was the highest in the surface layer. Downwards till the depth of 8 cm it decreased, then to the depth of 30 cm it remained constant and equal to 18—18,5 per cent and in the transitional zone of the incomplete wetting it decreased abruptly to 2 per cent in the layer from 40 to 45 cm. The zero time suction curve proves the suction to be maximum at the depth of 21 cm and from this point it somewhat decreases upwards and downwards. Thus from the very start a small positive gradient directed downwards is formed in the layer with constant moisture content (8—27 cm) as well as in the layer with the opposite direction of moisture gradient (0—8 cm). The suction gradient causes the ascending moisture movement from the dryer layers to the wetter ones.

In the first twenty-four hours (curves 1) the moisture content in the wetted layer decreases slightly, but the direction and magnitude of the moisture gradient remain almost the same as in the initial stage in the layer up to 25 cm, the suction gradient increasing distinctly in the layer from 5 to 21 cm, and having opposite direction to the moisture gradient.

In the second twenty-four hours (curves 2) the moisture content decrease proceeded. However the moisture content increase in the layer 30—45 cm testifies that the moisture content decrease in the upper 30 cm layer is caused by percolation during 2 days. At that moment (curves 2) in the upper 8 cm layer the moisture content decreases downwards as before. In the layer 8—22 cm it is nearly constant and equals to 17 — 17.3 per cent i.e. near to field capacity. At the same time suction has maximum magnitude in the layer 16—26 cm. In the upper part of the loam (up from the depth of 16 cm) a very distinct suction gradient is observed, especially in the layer 8—16 cm

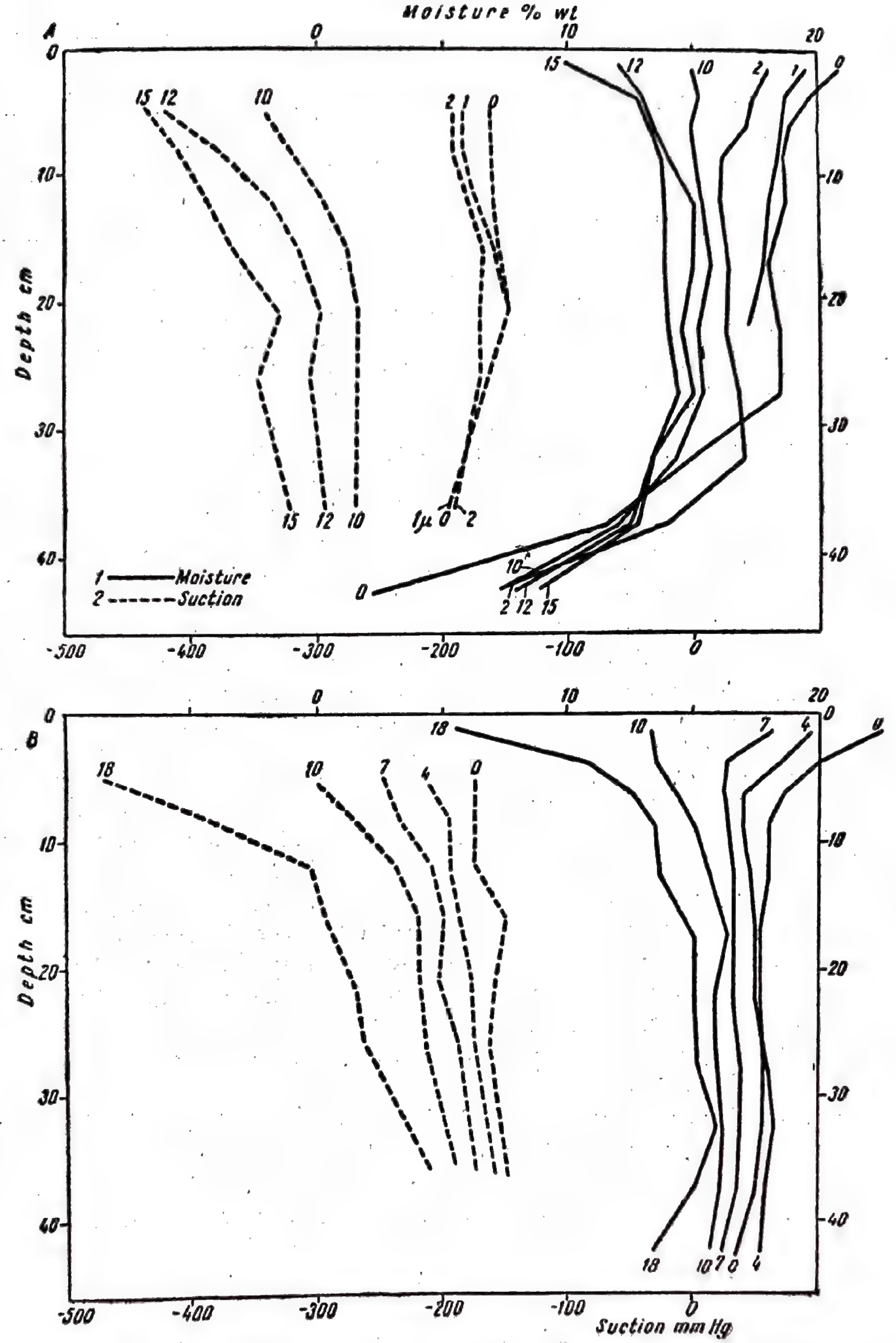

Fig. 1. *A* — Experiment 1. Moisture change and suction change during the suspended moisture evaporation process. The figures near the curves show the number of days since the beginning of evaporation; *B* — Experiment 2. Moisture change and suction change during the suspended moisture evaporation process. The figures near the curves show the number of days since the beginning of evaporation.

Subsequently the factor necessary to the ascending water movement becomes stronger and as previously the suction pressure gradient has the direction opposite the moisture gradient direction. In the layer 22—32 cm the moisture content slightly increases downwards and suction decreases in the same direction. It means that the direction of these two gradients are opposite.

In the next 8 days (curves 10) one may observe the significant decrease in moisture content throughout the wetted layer. The cause is evaporation only, as the lower ends of the curves coincide and this indicates the absence of infiltration. The moisture content from the surface to the depth of 30 cm is nearly constant and equal to 15 per cent. It means that the moisture gradient is nearly zero. The moisture loss is going on throughout the whole wetted layer. At the same time suction decreases strongly and in the layer 5—16 cm its gradient increases significantly with zero moisture gradient. In the layer deeper than 16 cm the suction gradient decreases gradually and becomes zero from the depth of 21 cm. At the same time the moisture content decreases strongly in the layer 27—37 cm.

Thus, the suction gradient in this layer, while equaling zero, does not correspond to the moisture gradient which is positive directed upwards.

In the next two days the moisture content distribution changes greatly in the upper layers. The superficial layer begins to dry and the minimum moisture content is observed at the surface. It testifies that the rate of the moisture rise has decreased so greatly that it cannot compensate the moisture spent on evaporation, and the moisture content in the upper layers decreases more rapidly than in the lower ones. From this moment the moisture gradient direction coincides with the direction of the suction gradient and their discrepancy disappears in the layer where it had been especially distinct. However, in the deeper layers the lack of correspondance is preserved. The moisture loss is going on in the whole wetted layer (curves 12 and 15), the moisture gradient being preserved at zero or nearly zero in the layer from 8 to 27 cm. At the same time the suction gradient increases and the suction itself decreases algebraically. In the lower layer (27—37 cm) the direction of the moisture gradient becomes opposite to the suction gradient direction (curves 12 and 15).

The second experiment (fig. 1B) gives similar results. It is significant, that due to the longer laps of time between the wetting of the loam and the beginning of evaporation there was no infiltration at the first period of evaporation, evaporation being responsible for the whole moisture loss and moisture distribution in the loam layer. We shall not consider the second experiment results in detail as the results of the two experiments are alike.

In conclusion it may be said that in the process of the suspended moisture evaporation from the wetted layer, in different parts of this layer a distinct discrepancy between the direction of moisture gradient and the direction of suction gradient may appear. This is why it is impossible to judge on the

direction of the suction gradient from the direction of the water content gradient. In this case the upward water movement proceeds according to the direction of the suction gradient, in some cases from the dryer layers to the wetter ones.

How can the opposite directions of the moisture gradient and of the suction gradient be explained? It may be assumed that this is caused by the hysteresis which is peculiar to the relation between moisture content and suction. It is well known that the curve describing this dependance has a hysteresis loop. The lower branch of the curve corresponding to the wetting is drawn beneath the upper branch (corresponding to the drying). That is why for the same magnitude of the moisture content in the wetting phase corresponds a lower (algebraically) suction than in the drying phase. Subsequently when the wetting of the upper soil horizons is replaced by their drying, the suction in them decreases without a content moisture change. This phenomenon may be the reason for the appearance of the suction gradient which causes the moisture rise from the layers with greater suction but with lower moisture content to the layers with lower suction but with greater moisture content.

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SUMMARY

1. During evaporation of suspended water the moisture and suction gradients in various parts of the wetted layer may present opposite directions.

2. In the first period of evaporation, the suction gradient is positive downward and moisture moves opposite to suction gradient, i.e. from higher to lower suction. At the same time the moisture gradient has an opposite direction, i.e. the moisture moves from dryer layers to wetter ones.

3. Subsequently, the moisture gradient decreases gradually to zero. At the same time the suction gradient increases significantly, keeping its initial direction. As evaporation proceeds, the moisture gradient takes the same direction as the suction gradient and at the soil surface a dried layer is formed. The opposite character of moisture and suction gradients is due to hysteresis.

RÉSUMÉ

1. Les gradients d'humidité et de succion peuvent, pendant l'évaporation de l'eau suspendue, présenter, dans les différentes parties de la couche humide, des directions contraires.

2. Pendant la première période d'évaporation, le gradient de succion est positif en sens descendant et l'humidité circule contrairement au gradient de succion, c'est à dire d'une succion élevée vers une plus réduite. En même temps, le gradient d'humidité a une direction opposée, c'est à dire l'humidité circule des couches à humidité plus réduite vers les couches à humidité plus élevée.

3. Ultérieurement le gradient d'humidité décroit petit à petit et devient nul. En même temps, le gradient de succion augmente sensiblement, tout en maintenant sa direction initiale. À mesure que l'évaporation continue, le gradient d'humidité prend la même direction que le gradient de succion formant ainsi à la surface du sol une couche sèche. C'est l'hystérésis qui constitue la cause du caractère contraire des gradients d'humidité et de succion.

ZUSAMMENFASSUNG

1. Bei der Verdunstung des hängenden Wassers können die Feuchtigkeits- und Saugspannungsgradienten in verschiedenen Teilen der befeuchteten Schicht, entgegengesetzte Richtungen aufweisen.

2. In der ersten Verdunstungsperiode ist der Saugspannungsgradient in absteigender Richtung positiv, während die Feuchtigkeit sich entgegen dem Saugspannungsgradient bewegt, das heisst von einer hohen zu einer niedrigeren Saugspannung. Zugleich weist der Feuchtigkeitsgradient eine entgegengesetzte Richtung auf, und zwar bewegt sich die Feuchtigkeit von den Schichten mit geringerer Feuchtigkeit nach jenen mit höherer Feuchtigkeit.

3. Später vermindert sich allmählich der Feuchtigkeitsgradient und erreicht den Nullpunkt. Gleichzeitig steigt der Saugspannungsgradient merklich, wobei er die ursprüngliche Richtung beibehält. Zugleich mit dem Fortdauern der Verdunstung, nimmt der Feuchtigkeitsgradient dieselbe Richtung wie der Saugspannungsgradient an, wodurch an der Bodenoberfläche eine trockene Schicht entsteht. Die Ursache des entgegengesetzten Charakters der Feuchtigkeits- und Saugspannungsgradienten ist die Hysteresis.

DISCUSSION

S. ANDREI (République Populaire Roumaine). Je considère que le rapport du prof. A. A. Rode et de Mme dr. G. I. Romanova présente un intérêt particulier parcequ'il montre de manière expérimentale qu'au cours d'un processus d'évaporation, le transfert de l'eau a lieu en conformité avec le potentiel de la pression de l'eau des pores.

En ce qui concerne la discrépance apparaissant entre le gradient de la teneur en eau et le gradient de la succion, je me permettrais de vous présenter quelques considérations qui me semblent mieux expliquer le phénomène et ne demandent pas de faire appel à l'hysthéresis de la courbe succion-teneur en eau.

Comme on le sait de la théorie de séchage (Ligkov, 1950, 1956), le commencement d'un processus d'évaporation à la partie supérieure de la couche de sol signifie l'application d'une dépression à ce niveau. Par exemple, si l'état d'humidité du sol, à la couche limite, correspond à l'hygroscopicité maximum, la valeur de cette sollicitation sera de l'ordre de 50 atm (pF $\simeq$ 4,7). L'ordre de grandeur de l'énergie appliquée par ce séchage par aération a été montré justement dans le rapport que j'ai présenté aujourd'hui.

Cette sollicitation peut être comprise plus facilement si nous nous rapportons au cas d'un échantillon de sol qui a une plaque poreuse, avec des pores très fins à la partie supérieure, par l'intermède de laquelle nous appliquons de l'extérieur une dépression (vacuum). Dans ce cas un processus de drainage de l'eau va commencer, de la partie inférieure vers la partie supérieure de l'échantillon, c'est-à-dire du potentiel plus élevé vers celui plus bas, jusqu'à ce que le potentiel des forces de rétention, c'est-à-dire la succion matricielle, comme l'appelle L. A. Richards (1960), soit en mesure de compenser le potentiel qui tend à provoquer le drainage de l'échantillon de sol.

Dans le cas considéré dans le rapport de Mr. le prof. Rode aussi, le transfert de l'eau se trouvant dans les pores du sol a lieu conformément à la théorie du potentiel, c'est-à-dire du potentiel total plus élevé vers le plus bas. Dans ce cas, le potentiel total (θ) a l'expression suivante :

$$\theta = \theta_{\text{séchage}} + \theta_{\text{grav}} + \theta_s.$$

où: $\theta_{séchage}$ est le potentiel dû à la sollicitation de séchage et qui d'ailleurs est prépondérant au commencement du processus;

θ_g — le potentiel gravitationnel qui dans notre cas est négligeable vu la hauteur relativement réduite de la colonne du sol (environ 40 cm);

θ_s — la succion matricielle due aux forces d'interaction eau-phase solide.

A l'aide des tensiomètres on mesure en fait la pression de l'eau des pores au niveau considéré, c'est-à-dire la somme du potentiel de séchage et du potentiel matriciel, ou bien, en tenant compte du fait que le potentiel gravitationnel est négligeable, on peut dire qu'on mesure la valeur du potentiel total qui provoque l'écoulement.

Comme on l'a vu dans les graphiques présentés par les auteurs, la dynamique des courbes du potentiel total est en concordance avec celle des courbes de variation de la teneur en eau, au sens qu'en général le potentiel décroît vers la surface, ce qui détermine le sens de la circulation générale de l'eau, de la partie inférieure vers la partie supérieure, fait qui apparaît avec plus d'évidence dans le diagramme correspondant à l'expérience nr. 2. Le fait même que dans les deux premiers jours du commencement de l'évaporation, le potentiel baisse entre la profondeur de 20 cm et la profondeur de 40 cm, ce qui entraîne une augmentation locale de la teneur en eau dans cette zone, constitue une preuve supplémentaire que la circulation de l'eau s'effectue en conformité avec la théorie du potentiel.

Il est certain que l'hysthérésis de la courbe succion matricielle — teneur en eau joue un certain rôle dans le développement des processus de circulation de l'eau à travers le sol, mais dans le cas considéré par les auteurs son effet est compris dans les valeurs mesurées à l'aide des tensiomètres, parce que ces dispositifs (appareils) permettent de mesurer directement la pression de l'eau des pores. Mais ce rôle principal, dominant le développement de l'entier processus analysé, est joué par le potentiel de sollicitation d'évaporation appliquée à la surface du sol, potentiel qui est la cause du processus de drainage (séchage) par aération.

En relation avec tout ce que j'ai montré auparavant, je considère qu'on devrait souligner encore une fois qu'on ne doit pas mettre le signe d'égalité entre la succion matricielle et le potentiel de la pression de l'eau des pores, qui est en dernière instance le facteur qui provoque, dans des conditions isothermiques, la circulation de l'eau du sol. [1]

A. A. RODE. I do not understand what the "drying potential" in your formula should mean.

S. A. TAYLOR (U.S.A.). It is well known that evaporating water requires a relatively large amount of heat to effect a phase change. It has also been established that the rate of supply of heat to the evaporating surface may limit the rate of evaporation [2]. What influence did the rate of heat supply have on your results?

A. A. RODE. The temperature factor does not play any role because the same results had been obtained without heating.

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AN EXACT THEORY OF SEEPAGE OF STEADY RAINFALL INTO TILE AND DITCH DRAINED LAND OF FINITE DEPTH[1]

DON KIRKHAM, W. L. POWERS[2]

INTRODUCTION

Vedernikov (1939), van Deemter (1949, 1950), Engelund (1951), and Polubarinova-Kochina (1962), have solved the problem of seepage of steady rainfall into drains, when the soil in which seepage occurs extends downward to infinite depth. The more practical problem, that where an impervious layer exists at finite depth, generally at shallow depth, has been solved approximately by Kirkham and Toksoz (1961). Our purpose here is to obtain an exact theoretical solution for both ditch and tile drainage for the finite depth problem.

ANALYSIS

The analysis of this problem depends on methods discovered by Kirkham (1964).

Figure 1 represents the problem we consider of ditch drainage. The distances s, h_s, h_e, and h_w are as shown, h_s and h_e being unknowns. Steady rain (or steady excess irrigation water) falls at a known rate R to maintain a water table EC. The ditch water height h_w is maintained by suitably outletting the ditches. The soil is of hydraulic conductivity k. The semispace $OABCEO$ is of particular interest and this is shown (fig. 2) as $OABCEO$, points C and E also being denoted by P_M and P_0.

In figure 2 a few flow lines are indicated above the water table arch EC. These flow lines are imagined as existing in a fictitious flow region. CDE that is now introduced to help solve the problem. In this fictitious region the real rain is replaced by a flow function $F(x)$, a function of x but not of time t, $[F(x) \neq R]$ to be distributed along ED in such a way that the

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[2] Professor of Soils and Physics, Curtiss Distinguished Professor of Agriculture; Research Associate.

segment DC of the ditch boundary will be a surface of seepage (as is also BC) and such that the water table arch CE will *(a)* be at atmospheric pressure and *(b)* receive amounts of water per unit horizontal distance x,

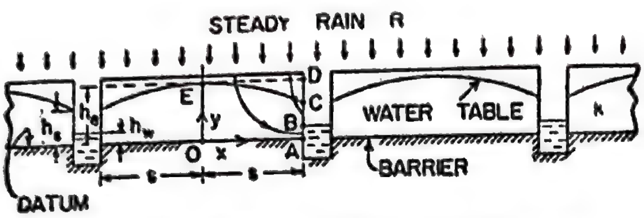

Fig. 1. The Geometry for ditch drainage.

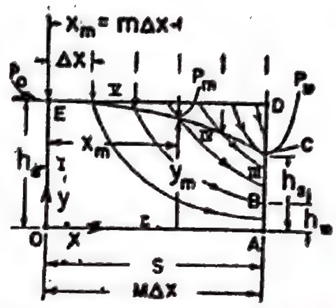

Fig. 2. Real and fictitious flow regions.

just as for the real rainfall condition. (We could specify other conditions for CD: we choose the condition that CD be a surface of seepage for convenience in later mathematical operations).

The fictitious region ECD, although water-saturated, will be under suction (compare Kirkham, 1964, fig. 1). The real region $OABCE$ will be under positive hydraulic pressure. Calculations may show points B and C coincide.

We will need to refer to a series of points $P_0, P_1, P_2, \ldots, P_m, \ldots, P_M$ on the water table arch, each a distance x apart where x must be related to M and s by $M\Delta x = s$ and where the coordinate x_m of the m-th point is $m\Delta x$, as indicated in Figure 2. The unknown y coordinates of the points are respectively y_0 $(=h_e)$, $y_1, y_2, \ldots, y_m, \ldots$ and $y_M(=h_s)$. The x coordinates of the points may be considered as known and are $x_0=0$, $x_1=1\Delta x$, $x_2=2\Delta x$, $\ldots$, $x_m=m\Delta x$, and $x_M=M\Delta x$ $(=s)$. The set of points may be denoted by $P_m(m\Delta x, y_m) = P_m(x_m, y_m)$ where $\Delta x = s/M$ and $m = 0, 1, 2, \ldots, M$.

The boundary conditions. Laplace's equation

$$\partial^2 \varnothing/\partial x^2 + \partial^2 \varnothing/\partial y^2 = 0 \tag{1}$$

must be satisfied subject to the boundary conditions. Here $\varnothing$, the potential or hydraulic head, is given by

$$\varnothing = y + p/\gamma g,$$

where p is the gauge pressure, γ the mass density of water and g the acceleration of gravity. The boundary conditions ($B.C.$'s) are (see fig. 2):

$$\begin{array}{llll}
\partial\varnothing\partial/x = 0 & x = 0 & 0 \gtreqless y \gtreqless h_e & B.C.I \\
\partial\varnothing/\partial y = 0 & y = 0 & 0 \gtreqless x \gtreqless s & B.C.II \\
\varnothing = h_w & x = s & 0 \gtreqless y \gtreqless h_w & B.C.IIIa \\
\varnothing = y & x = s & h_w \gtreqless y \gtreqless h_e & B.C.IIIb \\
\varnothing = y_m & x = x_m & \text{at and } P_m \text{ on } EC & B.C.IVa
\end{array}$$

$$\int_{x=0}^{x=x_m} k(\partial \varnothing/\partial y)_{y=y_m}\, dx = Rx_m \quad \text{at any } P_m \text{ on } EC \qquad B.C.IVb$$

$$k\partial\varnothing/\partial y = F(x) \qquad y = h_e \qquad 0 \gtreqless x \gtreqless s \qquad B.C.V$$

B.C.V will depend on *B.C.*'s *IVa* and the other *B.C.*'s. *B.C. V* need not be determined explicitly, neither for analytical or practical reasons. To get a flow net in the fictitious region, one would need *B.C.V*.

The potential function. In order to satisfy the boundary conditions, we choose, judiciously, the potential function $\varnothing$ in the form.

$$\varnothing = h_e \frac{A_0}{2} + \sum_{p=1,2,\dots}^{\infty} h_e A_p \frac{\cos h\,(p\pi x/h_e)}{\cos h\,(p\pi s/h_e)} \cos \frac{p\pi y}{h_e} + $$

$$+ \sum_{n=1,3,\dots}^{N} h_e B_n \cos \frac{n x\pi \cos h(n\pi y/2s)}{2s \cos h(n\pi h_e/2s)} \tag{2}$$

where A_0, A_p, B_n and N (on the second Σ) are constants to be determined.

We see from (2) and the *B.C.*'s that *B.C.*'s *I* and *II* are satisfied for any values of A_0, A_p, B_n and N and we see, by Fourier cosine series theory, that *B.C.*'s *IIIa* and *IIIb* will be satisfied by choosing A_0 and A_p to satisfy:

$$h_e A_0 = \frac{2}{h_e}\left[\int_0^{h_w} h_w \mathrm{d}y + \int_{hw}^{h_e} y\,\mathrm{d}y\right]$$

$$h_e A_p = \frac{2}{h_e}\left[\int_0^{h_w} h_w \cos \frac{p\pi y}{h_e}\mathrm{d}y + \int_{hw}^{h_e} y \cos \frac{p\pi y}{h_e}\,\mathrm{d}y\right]$$

which give, after integration and simplification

$$h_e A_0/2 = (h_e/2)(1 + h_w^2/h_e^2) \tag{3}$$

$$h_e A_p = -\frac{2h_e}{p^2\pi^2}\left(-\cos p\pi + \cos \frac{p\pi h_w}{h_e}\right). \tag{4}$$

With the A_0 and A_p as given by (3) and (4) we have all the *B.C.*'s satisfied except *IVa* and *IVb* (*B.C. V* will automatically be satisfied when the constants A_0, A_p, B_n and N are obtained).

Determination of the B_n *and* N — Use (2), (3) and (4) in *B.C. IVa*, and divide the resulting equation by h_e to find

$$y_m/h_e = (1/2)(1 + h_w^2/h_e^2)$$

$$-\sum_{p=1,2,\dots}^{\infty} \frac{2}{p^2\pi^2}\left(-\cos p\pi + \cos \frac{p\pi h_w}{h_e}\right) \frac{\cos h\,(p\pi x_m/h_e)}{\cos h\,(p\pi s/h_e)} \cos \frac{p\pi y_m}{h_e} +$$

$$+ \sum_{n=1,3,\dots}^{N} B_n \cos \frac{n\pi x_m}{2s} \frac{\cos h(n\pi y_m/2s)}{\cos (n\pi h_e/2s)}. \tag{5}$$

Then use (2), differentiated, in *B.C. IVb*, in which, after integrating, use (4).

Then divide both sides of the resulting equation by k and h_e, to find

$$\frac{R}{k}\frac{x_m}{h_e} = \sum_{p=1,2,\ldots}^{\infty} \frac{2}{p^2\pi^2}\left(-\cos p\pi + \cos\frac{p\pi h_w}{h_e}\right)\frac{\sin h\,(p\pi x_m/h_e)}{\cos\,(p\pi s/h_e)}\sin\frac{p\pi y_m}{h_e} +$$

$$+\sum_{n=1,3,\ldots}^{N} B_n \sin\frac{n\pi x_m}{2s}\,\frac{\sin h(n\pi y_m/2s)}{\cos h(n\pi h_e/2s)}. \tag{6}$$

Instead of using *B. C. IVb* (4), one could use, for getting (6), the relation, true by continuity,

$$\int_0^{y_m} - k\,(\partial\varnothing/\partial x)_{x=x_m}\,dy = Rx_m.$$

Equations (5) and (6) may be compressed to the respective forms

$$y_m/h_e = a_m + \sum_{n=1,3,\ldots}^{N} B_n b_{m,n} \tag{7}$$

$$(R/k)\,(x_m/h_e) = \alpha_m + \sum_{n=1,3,\ldots}^{N} B_n \beta_{m,n} \tag{8}$$

where a_m, $b_{m,n}$ are determined by comparing (5) and (7); and α_m and $\beta_{m,n}$, by comparing (6) and (8).

In (7) and (8) we are free to choose $N = 1,3,\ldots$ as we wish. Let us take $N = 3$ and expand (7) and (8) to find, respectively,

$$y_m/h_e = a_m + B_1\, b_{m1} + B_3\, b_{m3}, \tag{9}$$

$$(R/k)\,(x_m/h_e) = \alpha_m + B_1\,\beta_{m1} + B_3\,\beta_{m3}, \tag{10}$$

where we remember that the subscript m refers to a point $P_m = (x_m, y_m)$ on *EC* of figure 2. There is difficulty with (9) and (10) : There are three unknowns B_1, B_3, and y_m (y_m occurs in a_m, α_m, and the b_m's and β_m's) and only two equations; so y_m cannot be determined. To get the proper number of equations we can, taking $N = 3$ to be specific, consider three equally spaced points on EC a distance $\Delta x = s/3$ apart, the points thus being at $(0, h_e)$ $(s/3, y_1)$, and $(2s/3, y_2)$. Using equation (9) and (O, h_e) we obtain.

$$1 = a_0 + B_1 + B_3. \tag{11}$$

Rearranging equation (11) along with equation (10) applied to the points $(s/3, y_1)$, and $(2s/3, y_3)$ respectively, gives us the following set of three

simultaneous equations; the first equation stems from equation (5) and the second two stem from equation (6);

$$
\begin{aligned}
1 - a_0 &= B_1 + B_3 + O(R/k), \\
-\alpha_1 &= \beta_{11} B_1 + \beta_{13} B_3 - (x_1/h_e)\, R/k), \\
-\alpha_2 &= \beta_{21} B_1 + \beta_{23} B_3 - (x_2/h_e)\, (R/k).
\end{aligned} \tag{12}
$$

In equation (12) we now assign in the coefficients $a_0, \alpha_1, \alpha_2, \beta_{11}, \beta_{13}, \beta_{21}$ and β_{23} values of h_e and s; and assign also estimated values of y_1 and y_2 say $y_1^{(1)}$ and $y_2^{(1)}$. With these assigned and estimated values we then solve the simultaneous equations (12) for B_1, B_3, and R/k. These last three quantities are first estimates of $B_1^{(1)}$, $B_3^{(1)}$, and $(R/k)^{(1)}$. Using the values of $B_1^{(1)}$ and $B_3^{(1)}$ and previously estimated values of $y_1^{(1)}$ and $y_2^{(1)}$ in the right hand side of equation (9) we have

$$
\begin{aligned}
y_1^{(2)}/h_e &= a_1 + b_{11} B_1^{(1)} + b_{13} B_3^{(1)}, \\
y_2^{(2)}/h_e &= a_2 + b_{21} B_1^{(1)} + b_{23} B_3^{(1)},
\end{aligned} \tag{13}
$$

which are solved separately for better estimates $y_1^{(2)}$ and $y_2^{(2)}$ of y_1 and y_2. These values of y_1 and y_2 are used to recalculate B_1, B_3, and R/k in equation (12). The new values of B_1 and B_3 are then used in equation (13) to get still better values for y_1 and y_2. This is a simultaneous iteration process and it is continued until the values of B_1, B_3, and y_1, and y_2 do not change in some specified decimal place. Only a few interations are needed (about two or three to two decimal accuracy) if good estimates of the y's are made. Good estimates can be made with graphs.

To calculate the height of the surface of seepage (s, h_s) we return to equation (10) and use the last set of values for B_1, B_3, and R/k along with $x_M = s$, and $y_M = h_s$ and solve for h_s by iteration using Kitover's tables as cited in Kirkham (1964).

To get more B_m's than two, we must take larger values of N in equations (7) and (8). If we take $N = 5$ and then apply equation (8) to the points $(s/4, y_1)$, $(2s/4, y_2)$, and $(3s/4, y_3)$ and then write out equation (7) for the point (O, h_e) we get four simultaneous equations with $B_1, B_3, B_5, R/k, y_1, y_2$ and y_3 as unknowns. Again the y's are estimated and then improved by simultaneous iteration using the equation resulting from the expansion of equation (7) at $(s/4, y_1)$, $(2s/4, y_2)$, and $(3s/4, y_3)$. The height of the surface of seepage h_s is solved for by iteration from the expansion of equation (8) at (s, h_s). Continuing this way we can take N as large as we please to determine as many points on the surface EC as we wish.

Tile drainage. To solve the tile drainage problem the procedure is similar to the above but is somewhat more complicated because an extra parameter, the drain radius must be considered.

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SUMMARY

Exact analytical expressions have been obtained for the height of points on the water table in ditch drained land in which the ditches penetrate down to an impervious layer and where steady rain fall (or steady excess irrigation water) maintains a steady state water table arch. The solution for the corresponding tile problem may similarly be obtained.

RÉSUMÉ

On a obtenu des formules analytiques exactes pour la hauteur des points situés sur la nappe phréatique dans un terrain drainé par fossés, dans lequel les fossés pénètrent vers le bas jusqu'à une couche imperméable et où des précipitations constantes (ou de l'eau d'irrigation en excès constant) maintiennent une voûte du plan d'eau en régime stationnaire. La solution pour le problème correspondant du drainage par tuyaux pourrait être obtenue d'une manière semblable.

ZUSAMMENFASSUNG

Genaue analytische Formeln sind für die Höhenpunkte des Wasserspiegels in durch Graben dräniertem Gelände, in welchem die Drängraben zu einer wasserundurchlässigen Schicht hinunterdringen und wo ständige Niederschläge (oder ständiges Berieselungswasser im Überschuss) einen stationären Grundwasserspiegelbogen aufrechterhalten, erreicht werden. Die Lösung für entsprechende Röhrendränungsprobleme kann in ähnlicher Weise erlangt werden.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 6

THE FILTRATION OF WATER IN SOILS IN THE REGION OF THE LAMINAR FLOW

MIROSLAV KUTÍLEK[1]

The evaluation of the filtration flow of water in soils is based upon a form of Darcy's law. However, this law has a limited validity as has been discussed by a great number of workers e.g. the survey at Scheidegger (1957), and Slepička (1961). At low values of the hydraulic gradient I, the interface exerts an influence upon the filtration velocity of water in materials with a high dispersion degree as water has a restricted mobility, this is the case of the filtration of water in loamy and clay soils. Under these conditions Darcy's law is modified and the simplest form of the modifications is (Benetin, 1958):

$$v = k\,(I - I_0), \tag{1}$$

where v is the filtration velocity; I, the hydraulic gradient; k, the hydraulic conductivity; I_0, the threshold gradient necessary before the filtration can occur. From the point of view of rheology, the equation (1) will fit with the modified Bingham flow. However, it is probable that the soil water has not the properties of the Bingham material. On the basis of a mathematical analysis of all factors, Slepička (1961) has divided the filtration into 3 domains: the pre-linear, linear and post-linear regimes. In the pre-linear regime, he supposes validity of the relation

$$v = \alpha \left(\frac{n}{\gamma}\right)^{f-1} k^f\, I^f, \tag{2}$$

where the exponent f may reach the value > 1; n is the viscosity of water; σ, surface tension; α, coefficient depending on the action of the solid surface. Kutílek (1962) supposes in discussing the properties of the adsorbed water that the filtration flow of water in fine textured soils ought be a non-Newtonian one. Swartzendruber (1962) has compared the relation of flow velocity v versus hydraulic gradient I for the Newtonian, Bingham and non-Newtonian liquid flowing in a capillary tube. From this comparison,

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he considered the filtration flow of water in soils containing clay to be non-Newtonian. Several other authors cited by Swartzendruber have the same opinion. On the basis of the analysis of experimental data of 4 authors Swartzendruber proposed the following equation,

$$v = M\,[I - I_0\,(1 - e^{-I/I_0})], \tag{3}$$

where M is called the hydraulic conductance; I_0, the non-Newtonian index.

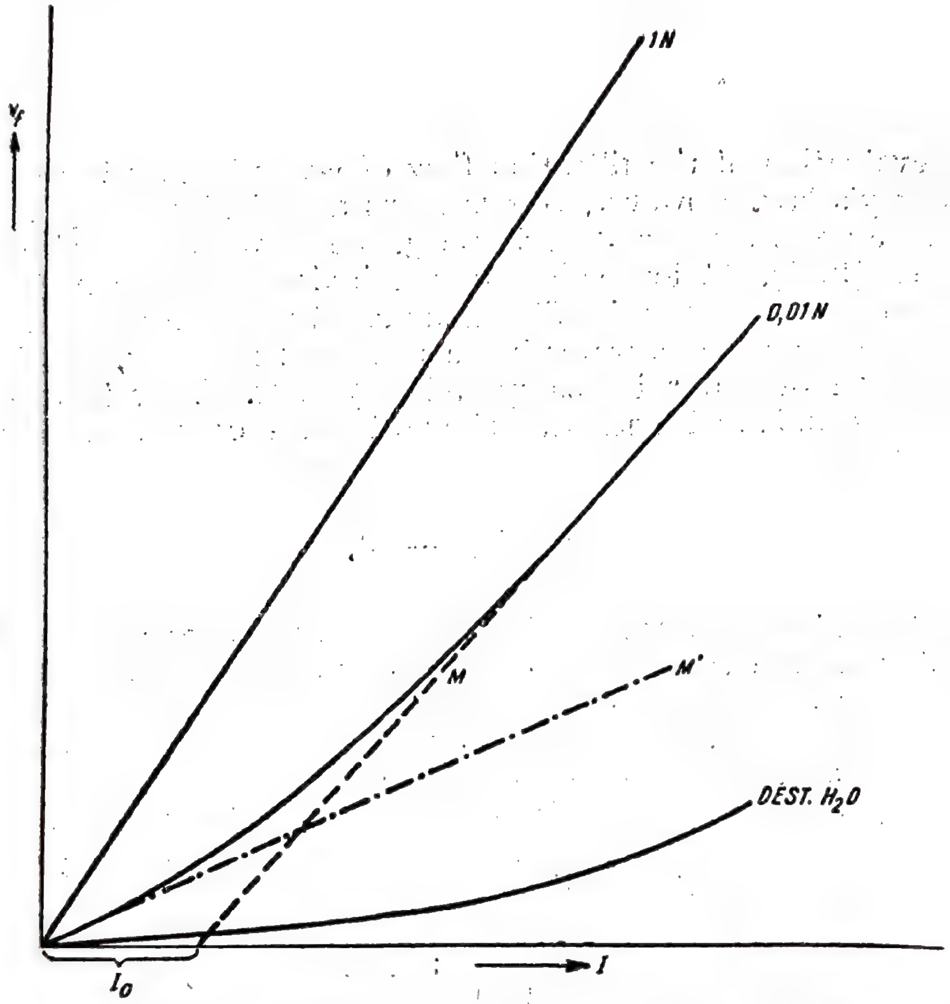

Fig. 1. General explanation of filtration velocity v and hydraulic gradient I for water and solutions of different concentrations. M is the hydraulic conductance, M' the initial hydraulic conductance, M/M' and I_0 are the characteristics of the non newtonian behaviour of soil water.

All the 3 mentioned equations are representative types of the modifications of Darcy's law and they are introduced in different variations by various authors.

To clear up the problem of filtration in the direct vicinity of the origin and to check the most suitable equation, model filtration experiments have been conducted. Clay fractions mineralogically homogeneous and homoionic (H, Na and Ca derivates) were used as the model material, viz,

kaolinite (Horní Bříza), montmorillonite (Braňany), illite (Vernéřovice), all from Czech locations. The basic parameters of these materials have been determined in a previous research, e.g.: soil specific surface, adsorption heat and adsorption water capacity from BET isotherms, wetting, heat pF curves, contact angle etc., (Kutílek (1962) and (1964). Because of the maximum development of the surface phenomena of these materials, the shape of curvature in graph v versus I and all factors influencing filtration can be more exactly determined. Destilled H_2O and the solution HCl, NaCl, Na_2SO_4, $CaCl_2$, $Ca(NO_3)_2$ in different concentrations were used for filtration. The total number of filtration experiments was 36, each in 2 or 3 replicates. The hydraulic gradient was held in ranges from 0 to 500—600.

The filtration velocity v was plotted versus hydraulic gradient I (fig. 1). For distilled water, the results were curves in all cases, probably beginning at the origin, approaching at high I a straight line. The filtration velocity was the lowest when compared with the filtration of solutions. For low concentrated solutions curvature was less evident and in 4 cases of high concentrated solutions, the relationship v versus I as a straight line and the filtration velocity is in accordance with Darcy's law. Immediately after wetting, we got a sigmoidal shape in the relation v versus I for minerals with thixotropic properties and for these minerals about 10 days of rest in excess of water were necessary to get the general relation of figure 1.

CHECKING OF FILTRATION EQUATIONS

From graphs v versus I, the approximate values of M (hydraulic conductance acc. to the suggestion of Swartzendruber), M' (initial hydraulic conductance) and I_0 (intercept of M on I axis) were graphically determined. A suitable mathematical equation was searched for experimental data. The equation (1) and (2) does not fit with the data. However, it was likewise very difficult to determine the values M and I_0 from equation (3), as we got a curve in the graph I^2/v versus u/v instead of a straight line according to the Swartzendruber's. method M was therefore not a constant and there was no general agreement between the equation (3) and the experimental data.

The more suitable equation (4) was therefore developed on the basis of the analysis of curves v versus I as follows:

$$v = M\left[\frac{1}{B}\, ln\,(A + e^{BI}) - I_0\right], \qquad (4)$$

where

$$B = \frac{ln\, M/M'}{I_0},$$

$$A = M/M' - 1.$$

For the Newtonian flow $M = M'$ and $I_0 = 0$, therefore $A = 0$ and the equation (4) reduces to Darcy's law:

$$v = M\, I.$$

Equation (4) fitted well with the experimental data and with the published results of e.g. Benetin, Swartzendruber etc. The flow of water in soils is then characterized by the values M, M'; I_0, where M/M' and I_0 are the characteristics of the non-Newtonian behaviour of water.

ANALYSIS OF RESULTS

The values of M, M'; I_0 were determined according to the equation (4) and are shown in table 1. As it follows from these results, the high osmotic pressure of the solutions acts similarly to the high hydraulic gradient, disturbing

Table 1

Characteristic values of filtration flow in homoionic clay minerals. M is the hydraulic conductance; M', initial hydraulic conductance; I_0, intercept of M on I axis

Clay mineral and adsorbed cation	Liquid	I_0	M	M'
			cm. hour^{-1}. 10^{-3}	
H — Kaolinite	H_2O	160	23.7	1.5
	0.01N HCl	35	30.0	19.3
	0.001N HCl	105	24.6	8.3
Na — Kaolinite	H_2O	395	8.1	0.8
	0.1N NaCl	0	22.2	22.2
	0.01N NaCl	0	19.5	19.5
	0.01N Na_2SO_4	202	15.5	3.3
Ca — Kaolinite	H_2O	113	14.8	1.5
	0.1N $CaCl_2$	0	24.9	24.9
	0.01N $CaCl_2$	0	18.6	18.6
	0.1N Ca $(NO_3)_2$	20	16.4	10.2
	0.01N $Ca(HO_3)_2$	113	14.8	1.5
H — Montmorillonite	H_2O	171	1.60	0.13
	0.01N HCl	110	1.93	0.83
	0.001N HCl	138	1.45	0.37
Na — Montmorillonite	H_2O	340	0.35	0.07
	1N NaCl	97	31.2	5.3
	0.1NNaCl	255	12.7	1.13
	0.01N NaCl	325	8.4	0.10
Ca — Montmorillonite	H_2O	295	4.2	0.12
	1N $CaCl_2$	90	111	20
	0.1N $CaCl_2$	120	108	9.3
	0.01N $CaCl_2$	210	66	4.3
H — Illite	H_2O	260	18.2	1.1
	0.1N HCl	140	31.4	4.2
	0.01N HCl	160	24.5	1.5
	0.001N HCl	260	18	1.1
Na — Illite	H_2O	185	0.86	0.29
	1NNaCl	62	3.6	0.64
	0.1N NaCl	85	1.21	0.38
	0.01N NaCl	110	0.93	0.33
	0.1N Na_2SO_4	100	1.02	0.38
Ca — Illite	H_2O	230	13.2	1.5
	1N $CaCl_2$	150	20.5	4.2
	0.1N $CaCl_2$	185	15.4	2.2
	0.01N $CaCl_2$	210	13.8	1.5

the orientation of the water molecules, and the non-Newtonian flow is changed into a Newtonian flow. For the non-swelling minerals, the values of M are of the same order for both distilled water and solutions. It was impossible to prove the effect of the electroosmosis. The coincident valuesof M for distilled water and low concentrated solutions are not a satisfactory proof of the effect of electroosmosis.

The M values were compared with the parameters of the clay minerals and the following general relationship was determined:

$$M = f_1\left(\frac{1}{S}\right) f_2(C) f_3\left(\frac{1}{n_{AVK}}\right), \tag{5}$$

where S is the specific surface; C, the constant, both from the BET equation; n_{AVK}, the number of adsorbed molecular layers at adsorption water capacity.

It follows from the relationship (5) that the hydraulic conductivity is lower when the soil specific surface rises, which is a generally well known fact concerning the relation between the specific surface and the hydraulic conductivity. The influence of the constant C from BET equation is more remarkable. The constant C depends on the value of the adsorption heat q_L when the first monolayer is adsorbed on the solid phase according to the equation

$$C = e^{-(q_L - q_1)/RT} \tag{6}$$

where q_1 is the adsorption heat of the last molecular layer and it is assumed that q_1 is equal to the heat of condensation; R is the gas constant; T, the absolute temperature. It has been determined in previous researches (Kutílek, 1962) that the bivalent cations cause higher bounding energy for the water at the direct proximity of the solid surface while the more distant molecules have the same properties as free water. These cations destroy the orientation of water molecules in the external part of the water envelope. The value of the constant C is therefore high. Monovalent cations cause on the other hand a weaker bond of the first molecular layer, with a lower evolution of adsorption heat, but the more distant molecular layers are keeping the properties of the quasi-crystalline water influenced by the solid surface. The constant C has a low value when compared with the case of bivalent cations (see table 2). The first molecular layers take no part in the filtration of water. However, the properties of the more distant layers are more important. When their molecules are oriented and arranged under the influence of the solid surface, the mobility of these molecules is lowered and in this way filtration velocity is influenced too. That is why high values of C is accompanied with high values of M supposing the other conditions have not been changed. Even a moderate rise of soil specific surface, as by bivalent cations influence does not produce the reduction of the hydraulic conductance M because of the dominant action of C (see the values of M, S, C for Na, Ca derivates of kaolinites, montmorillonites and illites in tables 1 and 2). The measure of the non-Newtonian behaviour of water is

therefore dependent on the value of C; also, the rise of C causes the drop in non-Newtonian properties. Since the exchangeable cations exert their influence upon the constant C, there are possibilities of artificially changing the filtration velocity of a given soil material.

Table 2

Parameters of clay minerals: S is the specific surface; C, the constant from the BET equation; n_{AVK}, the number of adsorbed molecular layers at adsorption water capacity

Clay mineral and adsorbed cation	From BET equation		n_{AVK}
	S $m^2 . g^{-1}$	C	
H-kaolinite	8.41	16.75	4
Na-kaolinite	6.53	14.58	5
Ca-kaolinite	10.84	22.81	3
H-montmorillonite	256	6.14	5
Na-montmorillonite	189	5.04	>6
Ca-montmorillonite	342	10.50	5
H-illite	77.2	10.37	4
Na-illite	64.2	9.69	4
Ca-illite	81.1	11.15	4

The number of molecular layers at the hydrolimit adsorption water capacity (n_{AVK}) exerts a similar influence upon the value of M. For high values of n_{AVK}, the water molecules at great distance from the solid surface have a reduced mobility and the value of the hydraulic conductance is lowered.

A more detailed relationship than the general one (5) may possibly be elaborated after further experimental research and it is possible that the value of n_{AVK} will be omited.

As results from table 1 and in full accordance with relationship (5), the order according to the hydraulic conductance is: kaolinite $>$ illite $\gg$ montmorillonite and Ca $\gg$ Na.

It is concluded from all the mentioned facts that the filtration is influenced by 3 categories of soil water:

1. Unmoving (hold) water, the content depends on the hydraulic gradient I and is in correspondence with a definite soil moisture on the pF curve, the quantity is Q_U.

2. The water with the properties of the non-Newtonian liquid, the quantity is Q_{NN}.

3. The water with the properties of the Newtonian liquid, the quantity is Q_N.

All 3 categories are in their volume dependent on I. The total quantity of filtered water is $Q_F = Q_N + Q_{NN}$, where

$$Q_N = f\ (I^n),$$
$$Q_{NN} = f\ (I^{-m}),$$

where $m > 0$, $n > 0$.

1.5

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SUMMARY

The filtration velocity of water and different solutions respectively in homoionic clay minerals was determined. From the analysis of results, a filtration equation was developed. The flow of water in clay soils has the character of the non-Newtonnian liquid and M/M' and I_0 are the characteristics of the non-Newtonian properties of water. The hydraulic conductance M depends on the values of the specific surface S, on the constant C from the BET equation and on the number of adsorbed molecular layers at the adsorption water capacity.

RÉSUMÉ

On a déterminé la vitesse de filtration de l'eau et respectivement de diverses solutions dans des minéraux argileux homoioniques. A partir de l'analyse des résultats on a développé une équation de filtration. L'écoulement de l'eau dans des sols argileux a le caractère du liquide non-Newtonien et M/M' et I_0 ont les caractère des propriétés non-Newtoniennes de l'eau. La conductance hydraulique M dépend des valeurs de la superficie spécifique S, de la constante C de l'équation BET et du nombre des couches moléculaires adsorbées à la capacité d'adsorption en eau.

ZUSAMMENFASSUNG

Es wurde die Filtrationsgeschwindigkeit des Wassers beziehungsweise verschiedener Lösungen durch Homoionentonminerale gemessen. Von der Analyse der Ergebnisse ausgehend wurde die Filtrationsgleichung entwickelt. Die Wasserströmung in tonhaltigen Böden hat den Charakter der nichtnewtonschen Flüssigkeit wobei M/M' und I_0 die Kennzeichen der nichtnewtonschen Eigenschaften des Wassers sind. Die hydraulische Leitfähigkeit M hängt von den Werten der spezifischen S-Oberschicht, von der C-Konstante aus der BET Gleichung und von der Zahl der adsorbierten Molekularschichten bei der Adsorptions-Wasserkapazität ab.

DISCUSSION

G. H. BOLT (Netherlands). Did the author attempt to determine the v/I relationship both in forward and backward order (i.e. with increasing and decreasing I)? Could swelling phenomena possibly have played a role in the experiments discussed?

M. KUTÍLEK. The repetition of filtration experiments proceeded in every case from the lowest I to the highest one.

P. CELESTRE (Italy). How can you distinguish between Newtonian and non-Newtonian flow? Evidently they appear simultaneously in most of the practical cases; how can you evaluate quantitatively the flow in such cases, when the distinction is difficult or impossible?

M. KUTÍLEK. We suppose that there is the sum of the non-Newtonian and Newtonian flow from:

a) the comparison of the filtration curve with the flow curve (v/I in capillary tube) of Newtonian, non-Newtonian and Bingham materials;

b) the gradually change of the non-Newtonian curve into the Newtonian straight line due to the rise of the concentration of solutions.

We have no apparatus and experimental data for the quantitative computation of both the compounds of filtration flow, the Newtonian (variable) and the non-Newtonian one.

J. P. QUIRK (Australia). I would like to hear details of the apparatus used to obtain the results described by the author. The difference in permeability for montmorillonite when n NaCl and 0.01 n NaCl were used as permeants is much smaller than other people have obtained— What is the reason for this?

M. KUTÍLEK. The principle of the filtration apparatus: hydraulic gradient was regulated by underpressure under the sample, filtration quantity was measured by horizontal graduated capillary.

As for the relatively low differences in M, when different concentrated solutions were used in montmorillonites, I have not a sufficient explanation. Relatively greater differences are however in values M'.

D. KIRKHAM (U.S.A.). Have you considered that this non-Darcy type flow you have discussed may be more important for flow in unsaturated soil than for flow in saturated soil? The importance may be greater because in saturated soil the drainage is primarily through cracks, root channels, worm holes and large pores; whereas in water unsaturated soil, the flow would be in micropores or in thin surface layers.

M. KUTÍLEK. No.

INFILTRATION AND RAINFALL-RUNOFF AS AFFECTED BY SURFACE CRUSTS

D. HILLEL[1]

I. INTRODUCTION

The possibility of controlling and increasing the amount of surface runoff obtained from sloping lands is of great importance in arid and semi-arid regions. Large tracts of land which cannot be profitably cultivated in the conventional way (owing to unstable rainfall or unsuitable soil) can be made to supply runoff water to adjacent lands or to storage reservoirs. Runoff-inducement methods generally consist of treatments to smooth, seal and stabilize the soil surface. A review of practical methods for runoff inducement ("water harvesting") has recently been published by Myers (1963). The problem includes technological and economic aspects, but we shall deal here with the physical aspect of surface sealing and its effect on infiltration.

It is common knowledge that the infiltration capacity of a smooth-surface soil largely determines rainfall-runoff (Horton, 1939) and is itself affected by the physical condition of the soil surface layer. There is, however, a lack of exact knowledge (experimental as well as theoretical) of the functional dependence of infiltration capacity upon crust and soil parameters.

The downward infiltration of water into a uniform soil profile ponded at the surface has been studied intensively ever since the experimental work of Bodman and Colman (1943) and the theoretical analysis of Philip (1957). Rain infiltration into an uniform soil where rainfall intensity is lower than infiltration capacity has been studied by Rubin and Steinhardt (1963).

Attention has recently been focused upon the problem of infiltration into a layered soil. Takagy (1960) presented an analysis of the steady- state downflow of water through a two-layer soil into a free water table beneath. Where the upper layer is less pervious than the lower, negative pressure (suction) can develop in the lower layer and remain at a constant value throughout a considerable depth range. Takagi analyzed the conditions under which the constant-suction zone will develop, and showed that it must begin at the junction of the two layers. Zaslavsky (1962) described a similar system

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and calculated the conditions for the transition from saturated to unsaturated flow.

In the present paper the writer wishes to extend the existing theory to infiltration into a profile of deep, uniform soil overlain by a thin, dense crust, using certain simplifying assumptions pertinent to the problem of runoff inducement.

II. THEORETICAL

Existing infiltration theory is based upon the proportionality of flow-rate (the flux) to the potential gradient (Darcy's Law):

$$q = -k \frac{d\Phi}{dx}, \tag{1}$$

where q is the volume flux of water, y is the distance increasing along the flow direction, Φ is the potential (usually expressed in terms of equivalent hydraulic head) and k is the hydraulic conductivity.

In vertical flow the total potential head (Φ) is taken to include the gravitational head (z) and the pressure head (h). Disregarding osmotic or thermal effects,

$$\Phi = h + z, \tag{2}$$

where z is the vertical coordinate, decreasing in the downward direction. The flow equation thus becomes.

$$q = k \frac{d}{dz}(h + z) \tag{3a}$$

or:

$$q = k \frac{dh}{dz} + k. \tag{3b}$$

Equation (3b) explains the initial decrease of infiltration rate with time and the eventual establishment of a constant rate (often called the "final infiltration capacity"). As the length of the wetted soil $(z)_w$ increases, the pressure (or suction) gradient $\left(\frac{dh}{dz}\right)_{tz}$ at any particular depth in the transmission zone decreases in magnitude and after a while becomes negligible. Eventually the gravitational head gradient remains the only effective driving force. In a uniform soil, therefore, as time $\to \infty$, $q \to k_s$ (where k_s is the saturated hydraulic conductivity).

Now we wish to examine infiltration into a crusted soil. We shall assume the following:

1) Darcy's Law is valid for unsaturated as well as saturated flow;
2) unsaturated soil moisture is always under negative pressure (matric suction);

3) for unsaturated flow hydraulic conductivity is a unique and singlevalued function of matric suction;
4) the soil underlying the crust is homogeneous and semi-infinite in depth;
5) the crust capping the soil is homogeneous and relatively thin, and its saturated hydraulic conductivity is much lower than that of the underlying soil;

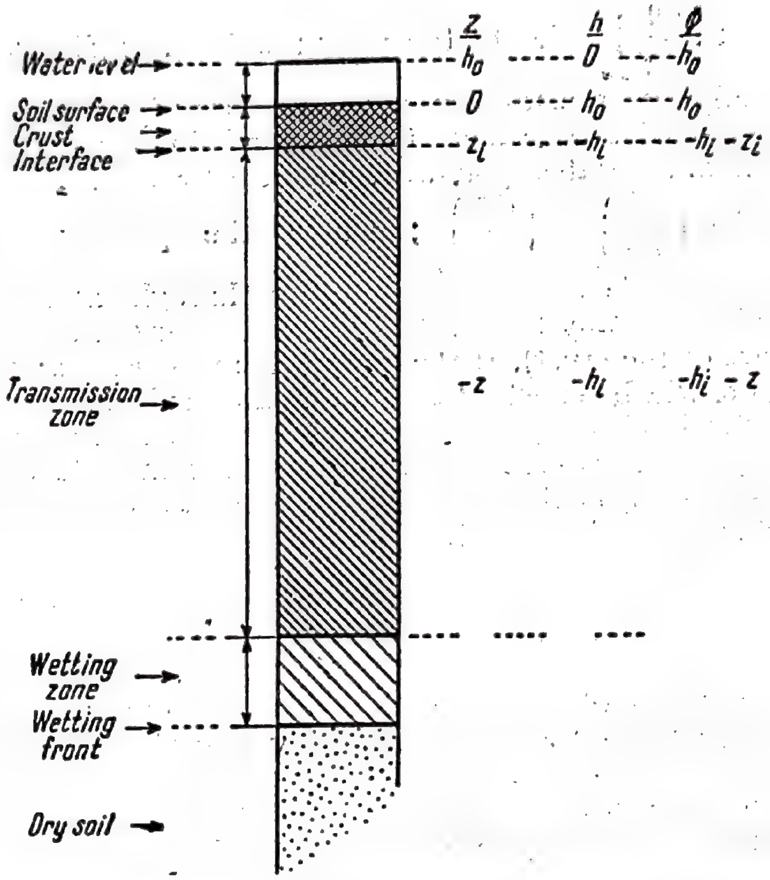

Fig. 1. The crusted soil profile during infiltration (under shallow ponding).

6) both layers are stable and there is no variation of conductivity with time due to physical, chemical or biological processes;
7) flow is one-directional only (vertically downward);
8) the water table is either non existent or too deep to affect conditions in the transmission zone.

Profile and flow conditions are shown in figure 1.

Disregarding the initial falling rate period of infiltration, we assume that after the wetting front extends well into the soil a stable moisture profile is maintained throughout the crust and transmission zone. Disregarding the wetting zone and wetting front, the flow through the crust and transmission zone thus continues under effectively steady-state conditions. Under such

conditions the flux through the crust (q_c) must equal the flux through the underlying transmission zone (q_u),

$$q_c = q_u$$

or:

$$K_c \left(\frac{d\Phi}{dz}\right)_c = K_u \left(\frac{d\Phi}{dz}\right)_u , \tag{4}$$

where $\left(\frac{d\Phi}{dz}\right)_c$ and $\left(\frac{d\Phi}{dz}\right)_u$ refer to the potential head gradients through the crust and underlying transmission zone, respectively. Since the gradient through the transmission zone tends to unity, it follows that this zone cannot become and remain saturated (for, when saturated $K_c \ll K_u$, and for $q_c = q_u$ it is necessary that $\left(\frac{d\Phi}{dz}\right)_c \gg \left(\frac{d\Phi}{dz}\right)_u$; where the positive pressure head acting on the crust surface is small, a gradient through the crust appreciably greater than unity can only form with the development of suction somewhere in the lower part of the crust). If the crust is homogeneous and saturated the gradient across it will be constant and the hydraulic head will decrease from h_0 at the surface *to* $-(h_i + z_i)$, where h_0 is the positive hydraulic head imposed by the surface-ponded water, h_i is the matric suction head at the interface of the layers and $-z_i$ is the depth of the interface below the soil surface (i. e. the thickness of the crust). Thus

$$q_c = k_c \frac{h_0 + h_i + z_i}{z_i} . \tag{5}$$

Under conditions of rainfall over a smooth sloping surface it can be assumed that only a thin "sheet" of water covers (or flows over) the soil surface and hence h_0 is negligible. Where the crust itself is very thin and of low conductivity, z_i will also be negligible in relation to the suction head at the interface, h_i. Hence the approximation

$$q_c = k_c \frac{h_i}{z_i} . \tag{6}$$

The condition that the crust remains saturated even while its lower part is under suction is that its critical air-entry suction (h_{ae}) be not exceeded (*i.e.* $|h_i| < |h_{ae}|$).

The underlying wetted soil, however, consisting of larger pores and subjected to suction h_i, will normally become unsaturated. Its unsaturated hydraulic conductivity (designated k_u) is not a constant (like k_c) but dependent upon the suction head. Since a uniform suction head prevails throughout the transmission zone, the only gradient present is that of the gravitational head, being unity. Therefore

$$q_u = k_u = q_c \tag{7}$$

and approximately

$$k_u = k_c \frac{h_i}{z_i} \tag{8a}$$

or

$$\frac{k_u}{h_i} = \frac{k_c}{z_i}. \tag{8b}$$

Several empirical expressions have been proposed for the relation of hydraulic conductivity to suction head under unsaturated conditions. Wesseling (1957) proposed

$$k = \frac{a}{|h|^n}, \tag{9}$$

while Gardner (1958) introduced

$$k = \frac{a}{|h|^n + b} \tag{10}$$

and

$$k = \frac{a}{e^{c|h|}}, \tag{11}$$

where $a, b, c,$ are empirical constants and $|h|$ is the absolute value of the matric suction head. Of these expressions Wesseling's is the simplest, though it cannot be used at or near saturation (where h approaches zero). Where k_c is very low, however, h_i will normally be appreciable. Combining equation (9), (7), and (8), we get either

$$\frac{a}{h_i^{n+1}} = \frac{k_c}{z_i}, \tag{12}$$

or

$$\frac{q^{\frac{n+1}{n}}}{\alpha} = \frac{k^{\frac{n+1}{n}}}{\alpha} = \frac{k_c}{z_i}, \tag{13}$$

where the right hand expression is the ratio of the hydraulic conductivity of the crust to its thickness and α is a constant equal to $a^{1/n}$. If the constants a and n are known, it is then possible to calculate the suction in the transmission zone of the underlying soil as well as the infiltration rate on

the basis of measurable crust properties. When the matric suction bears a known single — valued functional relation to water content, it should also be possible under the conditions described to calculate the moisture profile during infiltration.

$$q = \left(\frac{\alpha k_c}{z_i}\right)^{\frac{n}{n+1}}, \tag{14}$$

$$h_i = \left(\frac{a z_i}{k_c}\right)^{\frac{1}{n+1}}. \tag{15}$$

III. EXPERIMENTAL

1. Methods:

A series of infiltration trials was conducted with soil columns 7.5 cm in diameter and about 100 cm in length. The columns were constructed by joining 1,5 cm high rings, and filled with a sandy loam loessial soil from the Negev region of Israel. The soil was passed through a 2 mm sieve and packed uniformly to a bulk density of 1.44 g/cub. cm. by means of a wooden tremie-packer.

Thin discs (1.5 cm thick) of soil crusts of different hydraulic conductivities were formed by soaking and puddling soil samples in special molds. The dried crusts were then placed over the soil columns to form surface layers of low conductivities. Soft rubber gum was used to seal the edges of the crust discs against the walls of the column-tubes.

The bulk densities of the crusts were measured by the mercury-immersion method and found to be in the range of 1.50 to 1.68 g/cub. cm. Identical samples of crusts were tested to determine their hydraulic conductivities in specially-constructed permeameter cells. The k values of crusts were found to be in the range of 10^{-5} to 10^{-8} cm/s while the saturated hydraulic conductivity of the underlying soil was in the order of 10^{-3} cm/s.

The infiltration tests were conducted by flooding over the column surface with a constant head of 1 cm. Periodic measurements were made of infiltration rate. The process was continued for 10 hours after the infiltration rate decreased to a constant value. The surface water was then siphoned off and the columns were cut into sections for determination of water-content profiles.

2. Results:

a) *Infiltration moisture profiles*:

Figure 2 shows the moisture content distribution with depth, 10 hours after attainment of constant infiltration rate,

It is seen that the denser the crust, the lower the moisture content of the transmission zone in the underlying soil and the shallower the wetting depth at the end of the falling-rate period of infiltration. The transmission

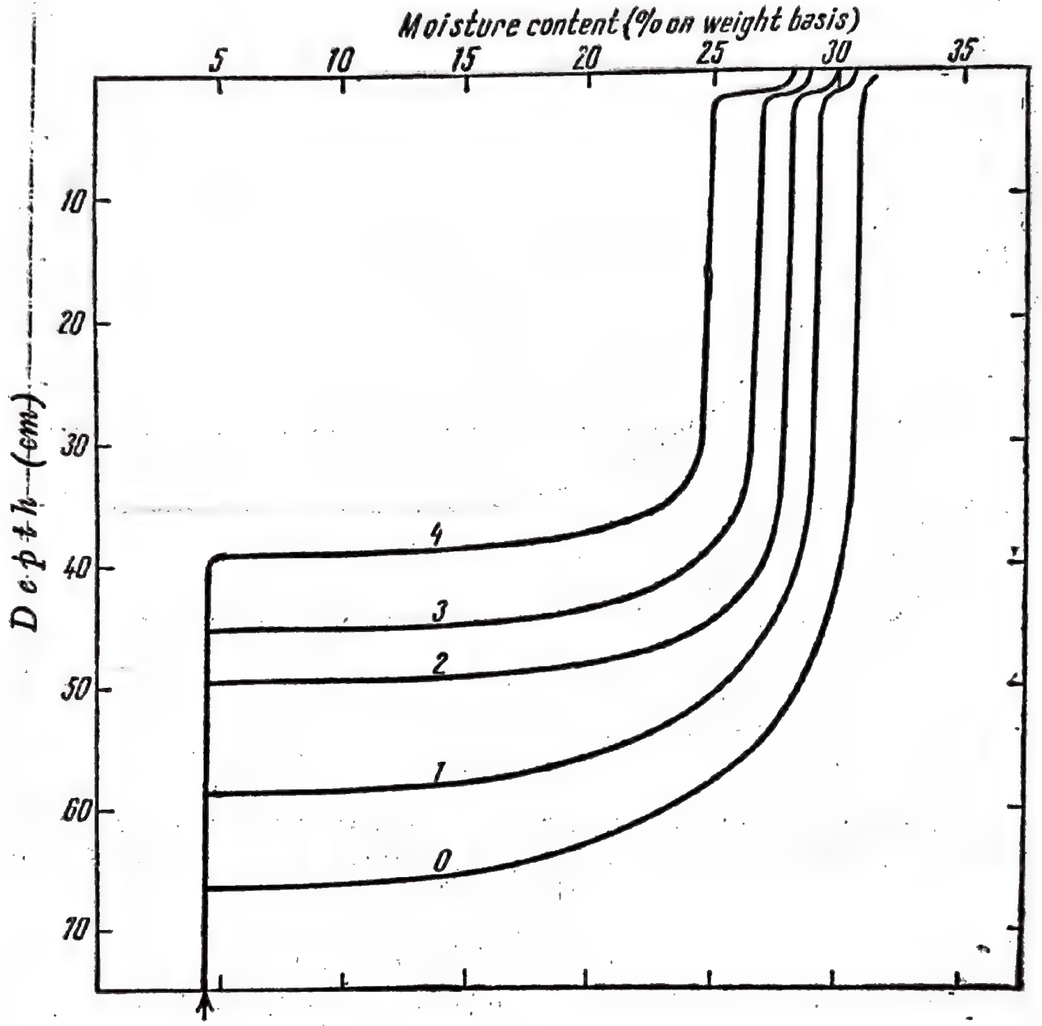

Fig. 2. Moisture content distribution profiles 10 hours after attainment of constant ("final") infiltration rate (curves 1, 2, 3, 4 are for columns with decreasing crust conductivity; curve 0 is for a non-crusted soil).

zone moisture contents shown in the graph (31.0, 29.6, 28.4, 27.0 and 25.1 per cent in decreasing order of crust conductivity) correspond approximately to suction head values of 5, 40, 70, 95 and 140 cm, respectively.

b) *Infiltration rates*;

Figure 3 shows the relation of infiltration rate to time for the various crust-capped columns.

The results of the constant-rate infiltration capacities accord in general with theory for measured crust conductivities, and a k versus h function (equation 9) of approximately $n = 2.8$ and $a = 7$ for the underlying soil.

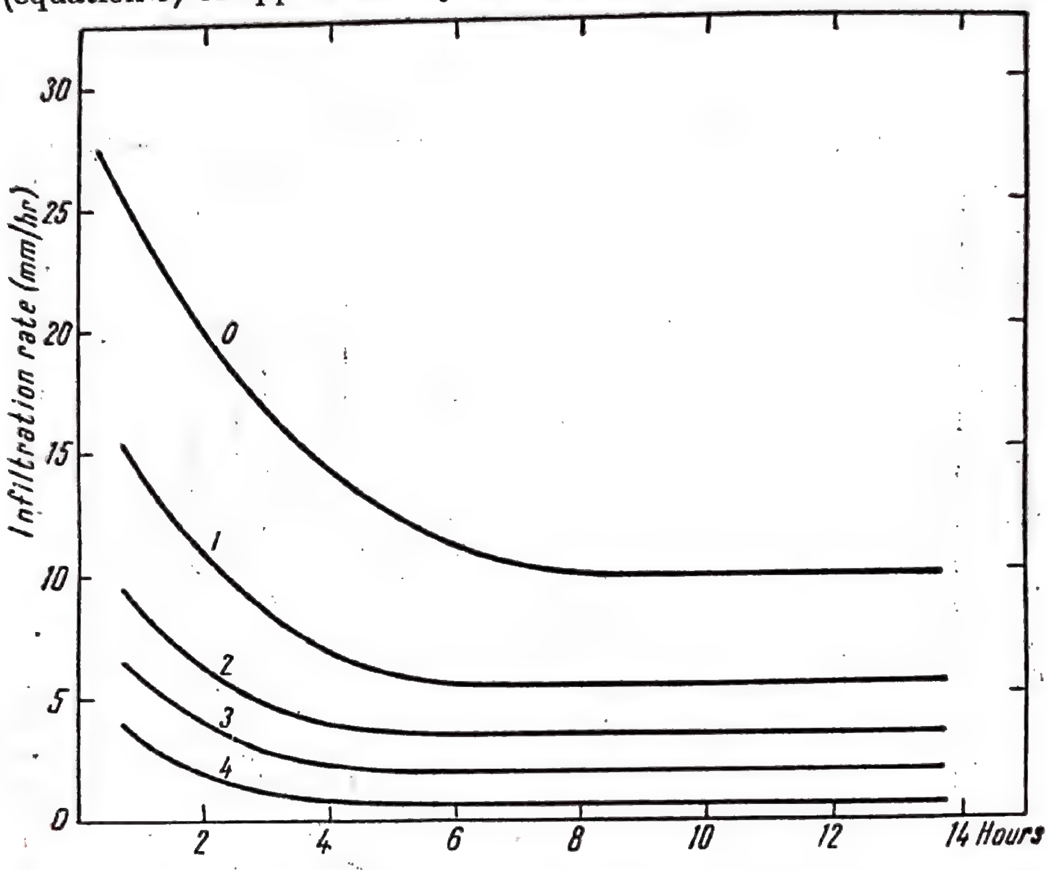

Fig. 3. Infiltration rate versus time for crust-capped columns (curves 1, 2, 3, 4 are for columns with decreasing crust conductivity; curve 0 is for a non-crusted soil).

IV. CONCLUSIONS

The theoretical considerations and experimental evidence presented indicate the possibility of predicting infiltration capacities and soil moisture profiles of crusted soils on the basis of measurable crust and underlying soil properties. The pertinent properties are the thickness and hydraulic conductivity of the crust; and the functional relation between hydraulic conductivity and matric suction as well as between matric suction and moisture content of the underlying soil.

Both the crust and the underlying soil are seen to affect infiltration capacity. This contradicts the oft-repeated notion that it is the least-permeable layer which alone controls flow rate in a layered soil. The two-layered soil profile described is a self-adjusting system in which the physical properties of the crust and underlying soil interact in time to form a stable moisture profile and constant infiltration rate, the magnitudes of which are determined mutually by the two layers. The suction which forms at the interface

of the layers is such as to create a gradient through the crust and a conductivity in the transmission zone which will result in an equal flux through both layers.

The approach of this paper is similar to that followed by Takagi (1960) to deal with the steady seepage from a ponded surface and through the soil to a phreatic water surface beneath. Strictly speaking, however, the simplifying assumptions employed (i.e. a thin and relatively highly impervious crust, a negligibly shallow water cover etc.) are applicable to special conditions only.

Exception can be taken to an approach based on the constant infiltration rate in disregard of the initial falling-rate period of the infiltration process. However, there is evidence to show that this initial period is short for dense crusts and premoistened soils. For all but the first rains of the season it is possible on a runoff inducement project to predict runoff-rates obtainable from smooth-surface soils on sloping lands, if rainfall data (number, sizes and intensities of rain storms) is available. Where artificial crusts are to be formed for the purpose of runoff inducement (either by causing the soil itself to crust or by coating it with a chemical agent) the approach presented can aid in determining the desirable crust properties.

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SUMMARY

The study is concerned with the effect of crust and soil properties on infiltration, under conditions pertinent to runoff-inducement projects in arid lands. Equations are developed to predict the relation of crust properties (thickness and hydraulic conductivity) and underlying soil properties (the functional dependence of conductivity and moisture content on matric suction) to infiltration. Experimental results accords with theory and show how the presence of a thin but dense surface crust can shorten the initial (falling-rate) period during infiltration, decrease infiltration capacity and affect the moisture content profile of the soil.

RÉSUMÉ

L'étude traite de l'effet des propriétés de la croûte et du sol sur l'infiltration, dans les conditions les plus favorables aux projets d'adduction de l'eau d'écoulement dans les terrains arides. On développe des équations pour prévoir la relation des propriétés de la croûte (épaisseur et conductibilité hydraulique) et des propriétés du sous-sol (dépendence fonctionnelle de la conductibilité et de l'humidité sur la succion matricielle) avec l'infiltration. Les résultats expérimentaux sont en concordance avec la théorie et prouvent que la présence d'une croûte de surface mince mais dense peut raccourcir la période initiale (à vitesse décroissante) de l'infiltration, baisser la capacité d'infiltration et influencer le profil d'humidité du sol.

ZUSAMMENFASSUNG

Der Aufsatz befasst sich mit der Auswirkung von Kruste- und Bodeneigenschaften auf die Einsickerung unter zu Abflusswasser-Zuführungsprojekten in Trockenland geeigneten Umständen. Gleichungen wurden entwickelt um das Verhältnis von Krusteeigenschaften (Mächtigkeit und hydraulische Leitungsfähigkeit) und Eigenschaften des unterliegenden Bodens (funktionelle Abhängigkeit der Leitfähigkeit und des Wassergehaltes von der Kapillarsaugung) zur Einsickerung vorherzusagen. Die Versuchsergebnisse sind mit der Theorie im Einklang und zeigen, dass das Vorhandensein einer dünnen aber dichten Oberschichtkruste die Anfangsperiode (Fallgrad) während der Einsickerung verkürzt, die Einsickerungsfähigkeit vermindern und den Wassergehaltprofil des Bodens beeinflussen kann.

DISCUSSION

S. A. TAYLOR (U.S.A.). 1. You assumed that $K_c \ll K_u$ hence $\left(\frac{d\mathfrak{h}}{dz}\right)_c \gg \left(\frac{d\mathfrak{h}}{dz}\right)_u$. Then you point out that $K_u = f\left(\mathfrak{h}\right)$ and stated that the system was self-adjusting. Will you justify further this assumption?

2. You indicated that runoff could be predicted from readily determinable soil parameters. What are these parameters and how are they determined? Can these parameters be determined independently of the particular system under consideration?

D. HILLEL. 1. The assumption is that the saturated conductivity of the crust is much lower than the saturated conductivity of the underlying soil $[(K_c)_{sat} \ll (K_u)_{sat}]$, and in the absence of a sizable positive head of water on the upper surface of the crust the crust cannot transmit a flux sufficient to keep the underlying soil saturated. Hence suction developes at the interface which at once increases the gradient through the crust and decreases the conductivity of the underlying soil.

2. For a smooth-surface, soil runoff rate can be assumed equal to the difference between the rainfall and infiltration rates. After an initial period infiltration rate drops to a constant value which we call infiltration capacity. Under conditions described, the infiltration capacity is determined by the following parameters: crust thickness and hydraulic conductivity, as well as the functional dependence of the underlying hydraulic conductivity upon its matric suction. Once these parameters are set they determine not only infiltration capacity but profile water-content distribution as well. K_c, z_i and K_u (h) can be determined independently. The equations presented for infiltration capacity proved valid in laboratory columns. We are now testing them in the field.

WATER MOVEMENT BELOW THE ROOT ZONE [1]

W.R. GARDNER [2]

Movement of ground water under saturated conditions has long been a subject of study and an extensive body of mathematical theory has been developed to describe this type of flow. Water movement within the plant root zone has received considerable attention in recent years and the equation for flow under unsaturated conditions has been applied to a number of important problems which occur in this region. However, flow between the root zone and the ground water has received much less attention and the theory for this region is less well developed. This paper deals with some aspects of water flow between the soil surface and the water table with emphasis on downward water movement. Such flow is particularly important under saline conditions where net downward movement of water must be maintained to provide adequate leaching and to prevent salt accumulation. For purposes of simplification, only one dimensional flow will be considered and the physical properties of the soil will be assumed to be uniform with depth.

STEADY-STATE FLOW

The simplest case is the steady-state case. For flow in either vertical direction, the steady-state flow equation may be written.

$$z = \int \frac{d\tau}{1 + q/k}, \tag{1}$$

where z is the vertical coordinate, τ is the matric suction, k is the unsaturated conductivity of the soil and q is the flux, which is positive in the positive z direction. The conductivity, k, is strongly dependent upon the

[1] This work was supported in part by the Meteorology Department, U.S. Army Electronic Research and Development Activity, Fort Huachuca, Arizona.

[2] Physicist, U.S. Salinity Laboratory, Riverside, California, U.S.A.

suction. For some soils the relationship between k and τ is given to an adequate degree of approximation by the empirical expression

$$k = K\left[\frac{1}{(\tau/h^n) + 1}\right], \tag{2}$$

K is the hydraulic or saturated conductivity of the soil, h is the value of the suction at which $k = K/2$ and n is a constant. The parameter h is of the order of 10 to 50 millibars suction and n ranges from about 2 for clay soils to as high as 10 for sands.

Solutions of equation (2) for several integral values of n have been published (Gardner, 1958). These may be applied to the case of downward water movement by appropriate evaluation of the constant of integration. For example, if $n = 2$, then:

$$z = \frac{Kh}{\sqrt{q(q+K)}} \tan^{-1} \quad \frac{\tau}{h} - \sqrt{\frac{1}{1+K/q}} + \text{constant.} \tag{3}$$

It can be shown by examination of equation (3) that when the water table is sufficiently far below the upper reference level, whether it be the soil surface or the bottom of the root zone, the downward flux q is independent of the depth z. Moreover, this flux is numerically equal to the unsaturated conductivity of the soil. It turns out that the soil-water content and the soil suction are virtually uniform with depth almost all the way down to the water table. The only downward water moving force is the gravitational gradient. The same situation exists for other values of n. This differs from the situation when movement is upward in which case the flux is strongly dependent upon water table depth (Gardner, 1958).

The criterion for the flux to be independent of water table depth, d, is that the latter must satisfy the inequality

$$d/2h > (K/q)^{1/n}. \tag{4}$$

When this inequality is not satisfied, the downward force is less than the gravitational gradient and the downward flux will be less than the unsaturated conductivity by a factor which can be calculated from the solution of equation (1). By way of exemple, let us consider a soil for which $K = 5$ cm/day, through which we wish to maintain a downward flux of 0.1 cm/day. If we take $h = 20$ cm and $n = 2$, then the depth from the bottom of the root zone to the water table must be at least 280 cm. Providing the water table is at least this deep, the downward flux is independent of the depth to the water table. The suction which must be maintained at the bottom of the root zone in order to achieve a given flux under these conditions can be evaluated from equation (2). In the example given here, $k = q = 0.1$ cm/day. Substituting values for k, K, and h into equation (2) gives $\tau = 140$ millibars. Thus, when the unsaturated conductivity of a soil is known as a function of the matric suction, it is possible to achieve a given percolation rate by maintaining the appropriate suction. Conversely the percolation rate can be estimated if the suction is known.

NON-STEADY-STATE FLOW

A truly steady-state condition is probably rare. Many transient problems can be considered in terms of one of three special situations. In the first case, it is assumed that steady-state conditions prevail initially and that a finite quantity of water is added to the soil as a single impulse at a time $t = O$. In terms of the hydraulic head, H, the flow equation in this case may be written.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(k \frac{\partial H}{\partial z}\right), \tag{5}$$

where t is the time and θ is the soil-water content on a volume basis. $H = -(\tau + z)$ when τ is expressed in the dimensions of head. If the change in water content is not too large, then $dH/d\theta$ is nearly a constant for any given water content and we can rewrite equation (5) to obtain.

$$\frac{\partial H}{\partial t} = \frac{\partial}{\partial z}\left[\left(k \frac{\mathrm{d}H}{\mathrm{d}\theta}\right) \frac{\partial H}{\partial z}\right] = D \frac{\partial^2 H}{\partial z^2}, \tag{6}$$

where D is the diffusivity, and $D = k\, \mathrm{d}H/\mathrm{d}\theta$ by definition. By assuming water content changes to be small, we may consider D to be a constant throughout the profile although D is normally a function of θ.

The solution of the flow equation under the conditions specified is given by Carslaw and Jaeger (1959, p. 259). The pulse of water moves downward approximately as a wave according to the equation

$$x = (2Dt)^{1/2}, \tag{7}$$

where x is the distance to the crest of the wave. The amplitude of the wave decreases as $1/x$. Thus, even though the assumption that the water content will change only slightly is not valid near the soil surface, it becomes more nearly true with depth and the approximation of a constant diffusivity becomes better and better as the wave proceeds downward. By the time the wave appears at the bottom of the root zone, this approximation should be very good.

If a relatively large quantity of water is added to the soil so that the average water content of the entire soil profile is increased well above the equilibrium or steady-state water content, a different initial condition must be specified. This is essentially the problem of the drainage of an entire soil profile which has been considered by Youngs (1960) and Gardner (1962a) among others. In that case, the rate at which water drains from the profile and enters the ground water system is given by

$$\mathrm{d}W/\mathrm{d}t = \frac{D(W - W_f)\pi^2}{4L^2}. \tag{8}$$

Where W is the total water content of the profile, W_f is the final equilibrium or steady-state water content of the profile and L is the depth to the water table. It can be shown that equation (8) is applicable even when the diffusivity is a function of the water content (Gardner, 1962b).

The third transient case to be considered is that in which water is added at regular intervals to the soil surface. If the flux of water into and out of the soil at the surface were a simple harmonic function of time, the water would appear to move downward into the soil as a series of waves with a velocity (Carslaw and Jaeger, 1959, p. 66).

$$v = (4\pi D/\Delta t)^{1/2}, \tag{9}$$

where Δt is the period, i.e., the time between irrigations or rainstorms. The wave length, or distance between successive waves, is given by

$$\lambda = (4\pi D\Delta t)^{1/2} \tag{10}$$

and the amplitude falls off as $\exp[-x\,(\pi/D\Delta t^{1/2}]$. The waves are virtually completely damped out by the time they have traveled one wave length into the soil. If we take the diffusivity of most soils to be of the order of 100 cm²/day at the so-called field capacity, a period of 10 days would give a wave length of 112 cm at this water content. In nature, water is not added to nor evaporated from the soil surface at a rate resembling a pure sine wave. However, whatever the shape of the curve, whether saw-tooth or square wave, it can be represented by a sine series. Because the higher frequency components of the series will be damped out most rapidly, by the time a wave reaches the bottom of the root zone, it should be virtually a sine wave. Individual rainstorms or irrigations will tend to merge as the depth increases and at depths of several meters only seasonal fluctuations will ordinarily be observed. The above analysis supports the suggestions by Gardner and Hillel (1962) that during evaporation from a soil, diurnal and even weekly fluctuations in the evaporation from the surface of the soil tend to be damped out and have only minor influence upon the rate of evaporation from depths of more than a few centimeters.

FIELD MEASUREMENT OF DIFFUSIVITY

The soil-water diffusivity provides a very useful measure of the depth of influence of any surface event. The equations for periodic boundary condition suggest a rather obvious method for the measurement of diffusivity in the field. By applying water to the soil at regular intervals and observing the rate at which the waves move downward, it should be possible to calculate the diffusivity in exact analogy to well known techniques for the measurement of thermal diffusivity. Preliminary experiments indicate that this procedure is indeed feasible, particularly if the soil suction is in the tensiometer range.

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SUMMARY

Solutions of the equation for flow of water in unsaturated soils are analyzed for both steady state and transient percolation. Under steady-state conditions, the rate of percolation is shown to be independent of the depth to the water table when the water table is sufficiently deep. In which case, the rate of water movement downward is equal to the unsaturated conductivity of the soil. Equations are given describing transient water movement for three different sets of boundary conditions. These equations permit the calculation of the rate at which surface variations in water content will be propagated downward and the depth to which they will be observed. The equation can also be used to determine the soil-water diffusivity from field observations.

RÉSUMÉ

Sont analysées les solutions de l'équation de l'écoulement de l'eau dans des sols non-saturés aussi bien pour la percolation sous régime stationnaire que pour la percolation transitoire. Dans des conditions de régime stationnaire, la vitesse de la percolation est montrée comme étant indépendante de la profondeur jusqu'au plan d'eau de la nappe phréatique, quand le plan d'eau est suffisamment profond. Dans ce cas, la vitesse du mouvement descendant de l'eau est égale à la conductibilité non-saturée du sol. Sont données des équations, qui décrivent le mouvement transitoire de l'eau pour trois états différents de conditions périphériques. Ces équations permettent de calculer la vitesse à laquelle des variations de l'humidité en surface seront propagées vers le bas et la profondeur jusqu'à laquelle elles seront observées. Les équations peuvent être utilisées aussi pour déterminer la diffusibilité de l'eau du sol à partir d'observations au champ.

ZUSAMMENFASSUNG

Lösungen der Gleichung für Wasserabfluss in ungesättigten Böden werden sowohl für stationäre als auch für vorübergehende Durchsickerung analysiert. Die Durchsickerungsgeschwindigkeit wird, unter stationären Bedingungen, als unabhängig von der Tiefe des Wasserspiegels angezeigt, wenn dieser genügend tief gelegen ist. In diesem Falle ist die abwärtsgerichtete Wasserbewegung der ungesättigten Leitfähigkeit des Bodens gleich. Es werden Gleichungen gegeben, die vorübergehende Wasserbewegung für drei verschiedene Lagen in Grenzbedingungen beschreiben. Diese Gleichungen erlauben die Berechnung der Geschwindigkeit mit welcher Oberflächenvariationen abwärts propagiert werden und die Tiefe zu welcher sie beobachtet werden. Diese Gleichungen können ebenfalls zur Festsetzung der Diffusionsfähigkeit des Bodenwassers von Feldbeobachtungen ausgehend benützt werden.

DISCUSSION

D. HILLEL (Israel). The use of a diffusivity value as a criterion for field capacity may be theoretically misleading. Diffusivity is the flux per unit gradient of moisture content. Water movement under the conditions described may occur at constant soil moisture content. Hence it seems preferable to relate the flux to hydraulic potential gradients and hydraulic conductivity rather than to moisture content gradients and diffusivity. For a deep uniform soil it may be possible to define field capacity (arbitrarily) in terms of the hydraulic conductivity.

W. R. GARDNER. I agree that it is probably better in this case to measure potential than mo isture content. However, the diffusivity appears in both the potential and water content systems under transient conditions. The potential diffusivity system is the most convenient mathematically.

S.A. TAYLOR (U.S.A.). Does the theory require that the initial water distribution throughout the profile be uniform and constant?

W. R. GARDNER. The initial moisture content need not be constant. However, the problem is much more complicated if it is not.

AL. FEODOROFF (France). Comment définissez-vous la capacité de rétention?

W. R. GARDNER. In order to define field or retention capacity adequately one must have some criterion for considering water content changes to be negligible. A rate of water content change which might be too small to detect in two or three days may make an important difference in two months. Thus, I would prefer not to define and precise field capacity. It should be pointed out that even though the water content throughout much of the root zone appears to remain virtually constant, there may be an appreciable rate of downward movement.

W.H. VAN DER MOLEN (Netherlands). Is the movement of moisture in the unsaturated state physically the same as the flow of heat, the diffusion of ions or the leaching of salts?

W.R. GARDNER. Different physical processes are involved, but the equations are the same mathematically as those for heat flow for which a large body of theory is available.

J. P. QUIRK (Australia). Dr. Gardner has shown a log-log plot of conductivity versus suction from which he obtains the exponent n. Do these measurements refer to disturbed or undisturbed samples. If the measurements are on disturbed samples, how were they prepared?

W. R. GARDNER : The data shown were for disturbed samples which had been packed to field bulk density, wetted, and partially dried two or three times. Data for field samples are in good agreement for values of the soil suction above about 200 millibars. At lower suctions the soil structure has a pronounced effect upon the conductivity.

G.H. BOLT (Netherlands). Would Dr. Gardner care to speculate on the experimental possibilities following from his approach? Might it be feasible to use very small pulses in connection with microsensors over short distances, or is the expected damping of the pulse such that considerable pulses would appear necessary. Could one perhaps apply a sinusoidal pulse and develop a standing wave against a reflecting surface?

W. R. GARDNER. Because of inhomogeneities in the soil and the rapid damping of the pulses with depth I think that micro-pulses would not ordinarily be used. There may be situations where one might wish to use them.

A.R. BERTRAND (U.S.A.). Mr. Elhira at Watkinsville Georgia U.S.A. is currently working with equipment for measuring micropulses. His data is preliminary, but looks very good at this time.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

ERGEBNISSE VON UNTERSUCHUNGEN ÜBER DIE WASSERBEWEGUNG IN UNGESÄTTIGTEN BÖDEN MITTELS DURCHFLUSSVERFAHREN

E. VETTERLEIN, R. KOITZSCH [1]

1. VORBEMERKUNG

Es werden in diesem Beitrag Ergebnisse von Untersuchungen der kapillaren Leitfähigkeit über den gesamten Bereich des pflanzenverfügbaren Wassers in verschiedenartigem Bodenmaterial und in homodispersen Kornfraktionen nach einem Durchflussverfahren mitgeteilt. Im Mittelpunkt der Untersuchungen steht der Versuch einer Gliederung verschiedenartiger Böden nach ihrer kapillaren Leitfähigkeit und die Frage der Kapillarrisserscheinung nach Rode (1959) und Abramova (1948).

2. UNTERSUCHUNGSMETHODE

Für die Bestimmung der kapillaren Wasserleitfähigkeit in dem Saugspannungsbereich von 0-1 at fand ein einfaches, in seinem Prinzip auf Richards (1931) zurückgehendes Gerät (Vetterlein, 1962) Verwendung (Abb. 1 A).

Für den Saugspannungsbereich von 1—15 at wurde von einem der Verfasser (Vetterlein, 1964a) ein Doppel-Membran-Gerät entwickelt, welches in seinem Prinzip einer Apparatur vor Richards und Moore (1952) entspricht, in dem aber anstelle von keramischen Platten Druckmembranen Verwendung finden, womit eine Ausdehnung des Messbereiches bis an den 15-at-Wert möglich geworden ist (Abb. 1, B).

Die Messungen der kapillaren Leitfähigkeit erfolgten bei stationärem Wasserdurchfluss, d.h. bei konstanten Mengen an Wasser, die pro Zeiteinheit in die Probe hinein und aus der Probe heraus geflossen sind.

Eine Bearbeitung der Theorie des Verfahrens wurde von Koitzsch (1964) vorgenommen.

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Die mitgeteilten Untersuchungen sind an Bodenmaterial mit zerstörter Struktur ausgeführt worden, und zwar an Bodenschichtdicken von 2 cm zwischen den porösen Platten und von 1 cm in dem Doppel-Membran-Apparat. Schrumpfungen der Bodenprobe finden bei der Berechnung der kapillaren Leitfähigkeitswerte Berücksichtigung.

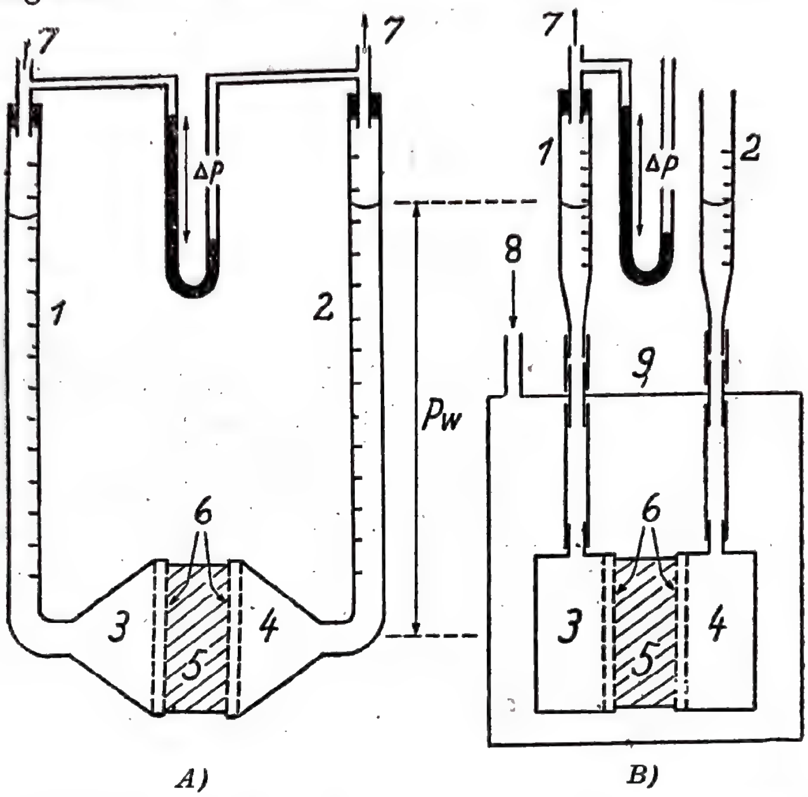

Abb. 1. Schematische Darstellungen der Versuchsgeräte: *A* —Durchflussapparatur mit Vakuumzellen (*1,2*— Büretten; *3,4* — Vakuumzellen; *5* — Bodenprobe; *6* — poröse Platten; *7* — zur Vakuumpumpe; Δ *P* —wirksame Druckdifferenz; *Pw*—Druck der Wassersäule); *B*—Doppel-Membran-Apparatur (*3,4* — Druckmembranzellen; *6* — Druckmembranen; *8* — Druckeinlass; *9* — Druckkammer; sonst wie *A*)

Zu Abbildung 1 A: Zwischen den Glastrichtern (*3,4*) mit porösen Platten (*6*) befindet sich die Bodenprobe (*5*). Die Glastrichter stehen mit je einer Bürette (*1, 2*) in Verbindung. Trichter und Büretten sind mit Wasser gefüllt. Durch Erzeugung eines um den Betrag Δ P differierenden Unterdruckes an den beiden Büretten wird ein Saugspannungsgefälle in der Bodenprobe erzeugt, und es setzt ein Wasserfluss durch die Bodenprobe ein, der nach einer unstationären allmählich in eine stationäre Phase übergeht.

Zu Abbildung 1 B: In dem Doppel-Membran-Gerät sind die Glastrichter durch Stahlkapseln (*3, 4*) und die porösen Platten durch Druckmembranen (*6*) ersetzt, die sich in einer Überdruckkammer (*9*) befinden. Die Druckkapseln stehen mit zwei Büretten (*1, 2*) ausserhalb der Druckkammer in Verbindung. Die erforderliche Saugspannungsdifferenz wird durch einen zusätzlichen Unterdruck ΔP an einer der beiden Büretten erzeugt. Die Bodenprobe (*5*) befindet sich in einem teleskopartigen Ring, der gewährleistet, dass auch bei Schrumpfungen der Bodenprobe der Kontakt mit den Membranen erhalten bleibt. Einzelheiten der Doppel-Membran-Apparatur sind in einer besonderen Mitteilung (Vetterlein, 1964 a) beschrieben.

Für die Berechnung der kapillaren Leitfähigkeit von Bodenproben ist es erforderlich, den Einfluss der Membranen bzw. porösen Platten zu berücksichtigen. Das geschieht, indem die Folge:

Membran-Bodenprobe-Membran als eine Aneinanderreihung dreier kapillarer Widerstände aufgefasst und die Berechnung in Analogie zu den Gesetzen des elektrischen Stromflusses oder des Wärmeflusses durchgeführt wird. Folgende Gleichung kann dafür benutzt werden (Koitzsch und Vetterlein, 1964)

$$k = k' \cdot \frac{1}{1-2\,\dfrac{k'/d}{k^*/d^*}} = k'\,\varepsilon',$$

k — kapillare Leitfähigkeit der Bodenprobe
k' — scheinbare kapillare Leitfähigkeit (Bodenprobe + Membranen)
k^* — kapillare Leitfähigkeit des Membran- bzw. Filtermaterials (k, k', k^* in ml cm^{-1} s^{-1} at^{-1})
d — Dicke der Bodenprobe (cm)
d^* — Dicke des Membranmaterials (cm)

Den durch die obige Gleichung definierten Korrekturfaktor zeigt die Abbildung 2 in Abhängigkeit von

$$\frac{k'/d}{k^*/d^*} = \mathrm{H}'$$

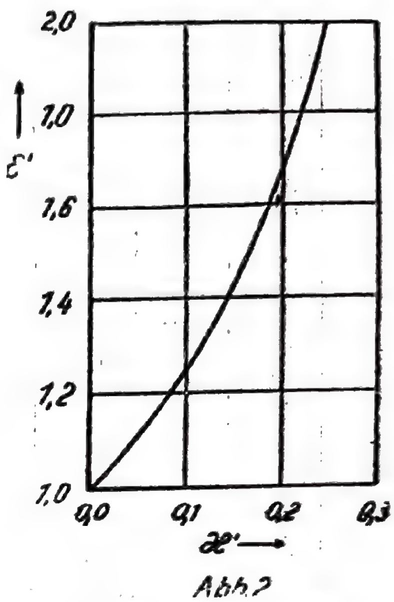

Abb. 2. Graphikum zur Korrektur des Einflusses der Membranen bzw. poröser Platten (s. Text).

Der Wert $\mathcal{H}'$ ist experimentell zu bestimmen, indem die scheinbare kapillare Durchlässigkeit der Bodenprobe k'/d (ml cm^{-2} s^{-1} at^{-1}) unmittelbar im Durchflussversuch und die kapillare Durchlässigkeit des Membran- bzw. porösen Plattenmaterials k^*/d^* (ml cm^{-2} s^{-1} at^{-1}) gesondert gemessen werden. Die Bestimmung der kapillaren Leitfähigkeit einer Bodenprobe ist, wie aus Abb. 2 ersichtlich, um so genauer möglich, je kleiner H′ ist, d.h. je grösser die kapillare Durchlässigkeit der Membranen bzw. Filterplatten im Verhältnis zur scheinbaren kapillaren Durchlässigkeit der Bodenprobe wird.

Bei Auswahl geeigneter poröser Filterplatten und Membransorten kann die Bestimmung der kapillaren Leitfähigkeit von Bodenproben im gesamten Bereich des pflanzenverfügbaren Wassers mit den beschriebenen Durchflussverfahren ausgeführt werden.

Alle Angaben der kapillaren Leitfähigkeit erfolgen in ml s^{-1} cm^{-1} at^{-1}, d.h. sie stellen die pro Flächen- und Zeiteinheit bei einem Saugspannungsgradienten von 1 at pro cm geflossene Wassermenge in ml dar.

3. ERGEBNISSE DER MESSUNGEN

Die im folgenden mitgeteilten Ergebnisse wurden von einem der Autoren (E. Vetterlein) gewonnen und erstrecken sich auf homodisperse Kornfraktionen und auf Material aus 16 verschiedenartigen Böden, deren Korngrössenzusammensetzung in Tabelle 1 mitgeteilt ist.

Tabelle 1

Korngrössenzusammensetzung der Böden zu den Abbildungen 6–9

Boden Nr.	2—1 mm	1—0,6 mm	0,6—0,2 mm	0,2—0,1 mm	0,1—0,06 mm	0,06—0,02 mm	0,02—0,01 mm	0,01—0,006 mm	0,006—0,002 mm	<0,002 mm
1	0,49	1,77	81,24	13,56	0,69	0,10	0,40	0,20	0,40	1,20
2	0,15	0,25	14,70	50,02	29,60	2,88	0,30	0,20	0,49	1,40
3	—	—	0,26	8,35	75,91	11,07	0,41	1,02	0,51	2,46
4	—	—	0,08	7,16	22,36	52,08	11,20	3,05	1,22	1,95
5	1,59	2,81	26,15	24,88	16,30	13,77	4,13	2,33	3,28	4,76
6	1,41	3,43	27,78	29,25	12,37	9,45	3,26	1,69	3,37	7,99
7	1,87	2,98	22,12	31,36	14,63	6,20	3,16	1,29	4,80	11,59
8	1,27	3,31	20,73	22,77	12,28	8,76	3,66	3,49	4,78	18,95
9	0,10	0,51	3,28	8,89	18,09	13,14	3,84	4,35	11,42	36,38
10	—	—	—	—	—	9,7	15,8	7,5	19,7	47,3
11	—	—	—	—	—	4,6	11,1	9,1	17,9	57,3
12	—	0,12	0,80	0,80	0,12	40,98	33,63	12,24	7,48	3,83
13	—	0,11	1,32	6,36	5,61	9,50	25,78	19,82	18,44	13,06
14	0,13	0,50	3,95	1,44	2,38	49,45	19,57	4,64	4,89	13,05
15	0,37	0,96	10,03	2,67	1,97	42,94	20,37	6,72	8,04	5,33
16	0,13	0,31	0,88	0,69	1,88	12,04	24,72	16,94	17,94	24,47

3.1. *Ergebnisse in homodispersen Kornfraktionen.*

Folgende Kornfraktionen von Mittelsand bis einschliesslich Grobton wurden aus natürlichem, vorwiegend aus Quarzen bestehendem Bodenmaterial durch Siebung, Schlämmung oder Zentrifugierung isoliert und untersucht (Durchmesserangaben in mm): 0,6—0,2; 0,2—0,1; 0,1—0,06; 0,06—0,02; 0,02—0,01; 0,01—0,006; 0,006—0,002; 0,002—0,001. Die Bestimmungen der kapillaren Wasserleitfähigkeiten erfolgten so, dass gleichzeitig anhand der Wasserstände in den Büretten die Änderungen im Wassergehalt der Fraktionen gemessen worden sind.

Die Ergebnisse dieser Untersuchungen sind in den Abb. 3 und 4 dargestellt. Es ist zu erkennen, dass in jeder der untersuchten Fraktionen nach

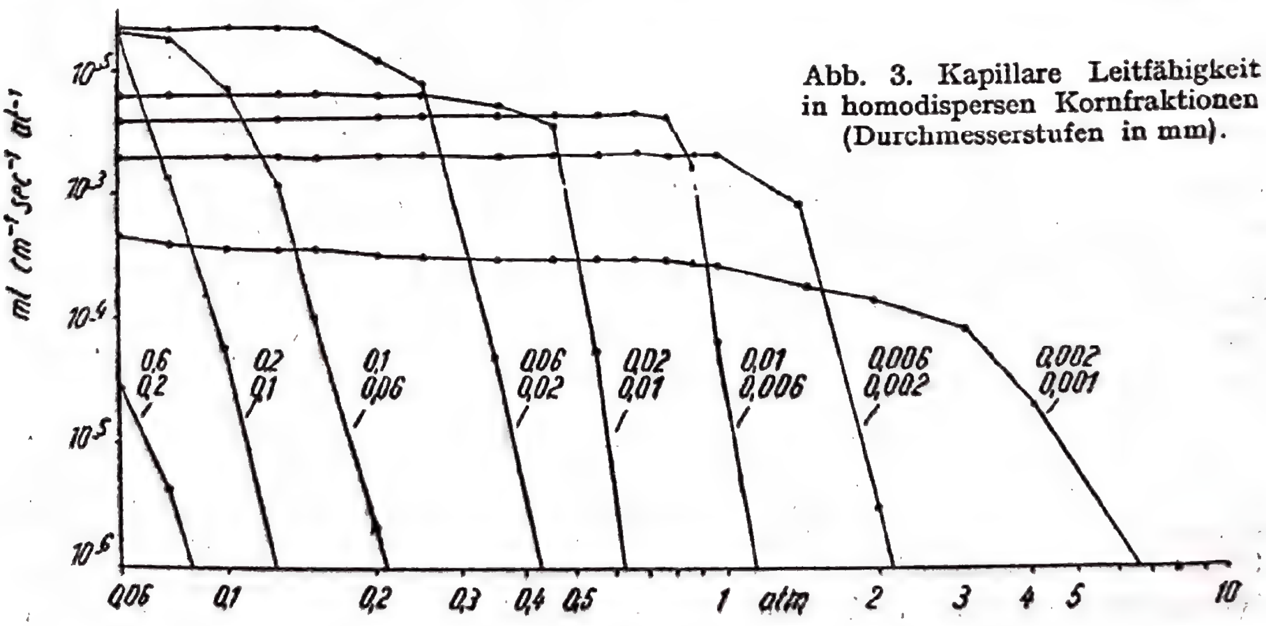

Abb. 3. Kapillare Leitfähigkeit in homodispersen Kornfraktionen (Durchmesserstufen in mm).

Tabelle 2

Kapillarrisswerte (at) von homodispersen Kornfraktionen (mm) (Mittelwerte aus mehreren Messreihen)

mm	at	mm	at
2 —0,6	0,0075	0,02 —0,01	0,45
0,6 —0,2	0,02	0,01 —0,006	0,85
0,2 —0,1	0,05	0,006—0,002	1,5
0,1 —0,06	0,1	0,002—0,001	3,0
0,06 —0,02	0,25		

einem Bereich gleichmässig hoher Werte ein plötzlicher steiler Abfall der kapillaren Leitfähigkeit erfolgt und zu Werten von fast Null führt.

Dieser steile Abfall in der Wasserbewegung ist, wie Abb. 4 erkennen lässt, verbunden mit einer Abgabe des grössten Teiles des in der Probe zuvor

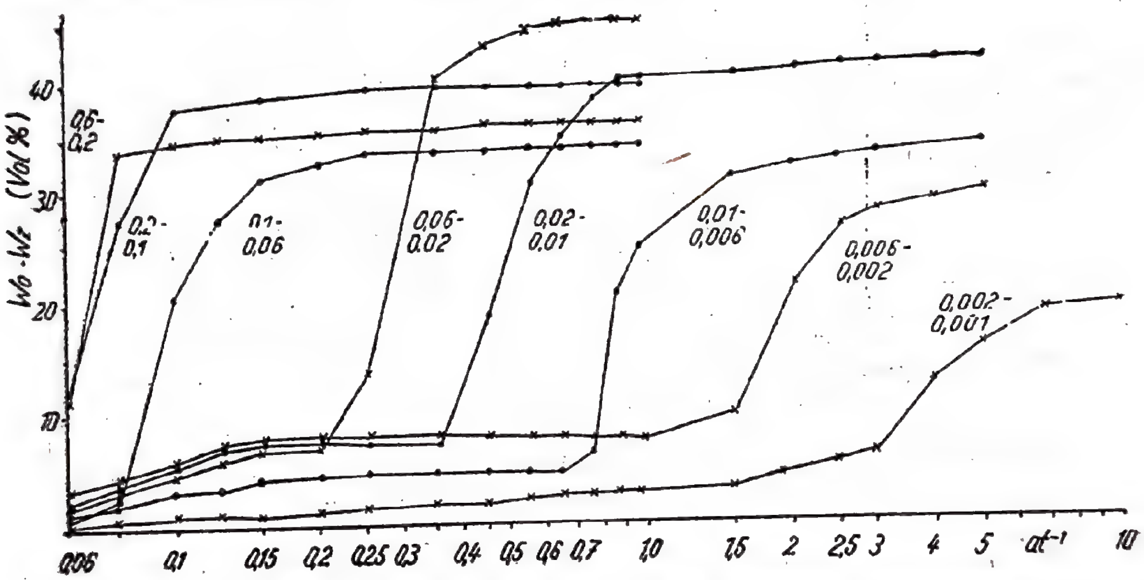

Abb. 4. Änderungen des Wassergehaltes (Wo—Wz) in Volumenprozent während der Durchfluss untersuchungen an homodispersen Kornfraktionen in Abhängigkeit von der Saugspannung des Bodens.

enthaltenen Wassers. Aus den abgegebenen Wassermengen (ca. 20—40 Volumenprozent) ist zu ersehen, dass die Proben im Bereich hoher kapillarer Leitfähigkeiten mit Wasser nahezu gesättigt sind, dass also mit der Wasserabgabe ein Übergang von der gesättigten, kapillaren zur ungesättigten, filmförmigen Wasserbewegung verbunden ist, d.h. ein plötzliches Abreissen der kapillaren Verbindungen erfolgt.

Bemerkenswert ist die Tatsache, dass selbst in der Fraktion 0,002—0,001 mm, die meist schon zu dem Ton gerechnet wird, sich ein deutlicher Kapillarriss vollzieht. Das Abreissen der kapillaren Wasserfäden erfolgt bei um so höheren Saugspannungswerten, je feinkörniger die Fraktion ist. Die Kapillarriss-Mittelwerte für die untersuchten homodispersen Korngrössen sind in Tabelle 2 wiedergegeben.

Ein deutlicher Zusammenhang besteht zwischen den Porengrössen in den einzelnen Fraktionen und dem jeweiligen Saugspannungswert beim Abreissen der kapillaren Wasserfäden. Diese Zusammenhänge sind in Abbildung 5 dargestellt. Die auf der Vorstellung eines Kugelmodells berechneten Porendurchmesser entsprechen bei lockerster Kugelpackung dem 0,42 fachen und

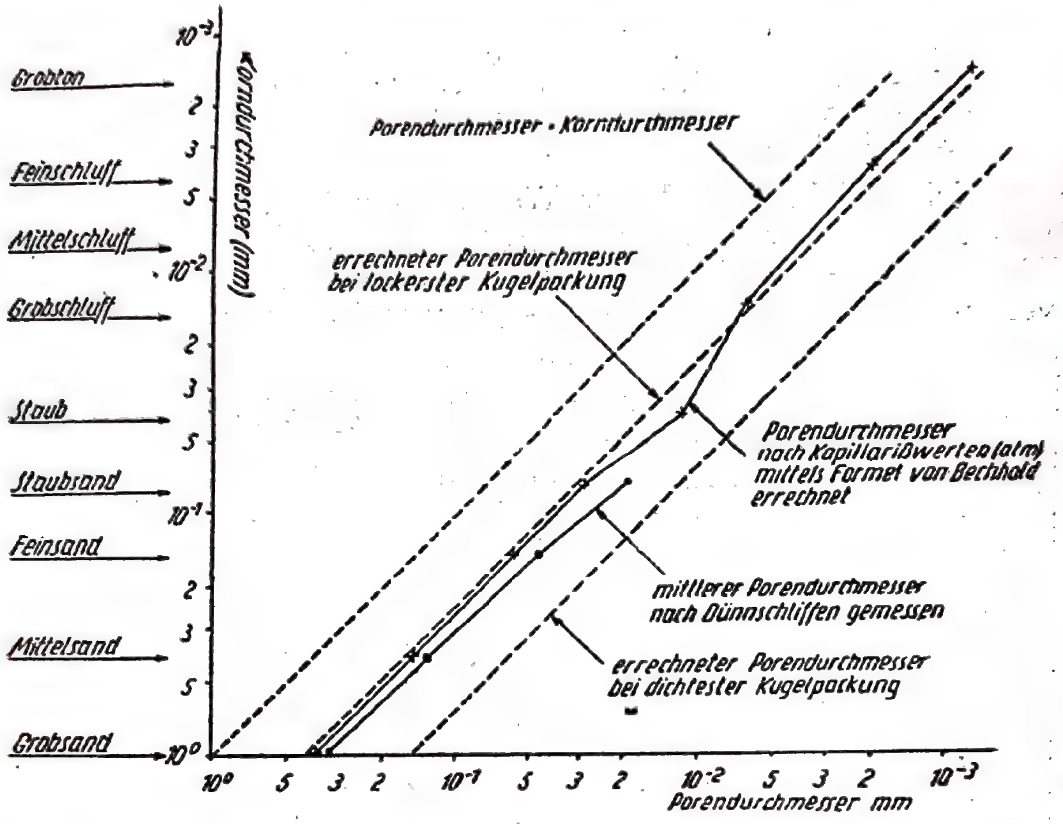

Abb. 5. Beziehungen zwischen Kapillarrisswerten (atm) und Porendurchmessern (mm) in homodispersen Kornfraktionen.

bei dichtester Kugelpackung dem 0,16 fachen des mittleren Kugeldurchmessers der jeweiligen Fraktion. Eine fast vollkommene Übereinstimmung ergibt sich zwischen dem "Porendurchmesser bei lockerster Kugelpackung" und dem nach der Bechholdschen Kapillaritätsformel (Bechhold, 1907; Einstein und Mühsam, 1923),

$$P = \frac{4\sigma}{2\gamma}$$

errechneten Porendurchmesser, wenn wir für P den Saugspannungswert beim Abreissen der kapillaren Wasserverbindungen einsetzen.

P — Notwendiger Druck zur Entleerung einer Kapillare in at,
2γ — Durchmesser der Kapillare in cm,
4σ — $0{,}296 \cdot 10^{-3}$ at · cm (bei + 20°C).

Die nach Ausmessungen von Dünnschliffen gemessenen mittleren Porendurchmesser liegen etwa zwischen dem Porendurchmesser bei lockerster

und demjenigen bei dichtester Kugelpackung. Insgesamt ergibt sich aus dem Dargelegten, dass das Eintreten des Abreissens der kapillaren Wasserfäden in homodispersen Kornfraktionen streng nach den Kapillaritätsgesetzen erfolgt und damit seine Erklärung findet.

3.2. *Messungen an verschiedenartigen Böden*

In Abbildung 6 sind Ergebnisse von Messungen der kapillaren Leitfähigkeit an Proben aus Sandböden, lehmigen Sandböden und einem sandigen Lehmboden dargestellt. Es ist sofort der deutliche Unterschied zwischen ton- und siltarmen Sandböden einschliesslich eines Staubbodens (1—4) einerseits, der lehmhaltigen Sande und Lehme andererseits zu erkennen. Erstere unterscheiden sich nicht wesentlich in ihrer kapillaren Wasserleitfähigkeit von den entsprechenden homodispersen Kornfraktionen. Nach hohen Werten bei geringen Saugspannungen, die um etwa 2—3 Grössenordnungen über denjenigen lehmiger Böden liegen, erfolgt ein plötzlicher steiler Abfall auf unmessbar kleine Werte. Bereits ein geringer Ton- und Siltgehalt, der den

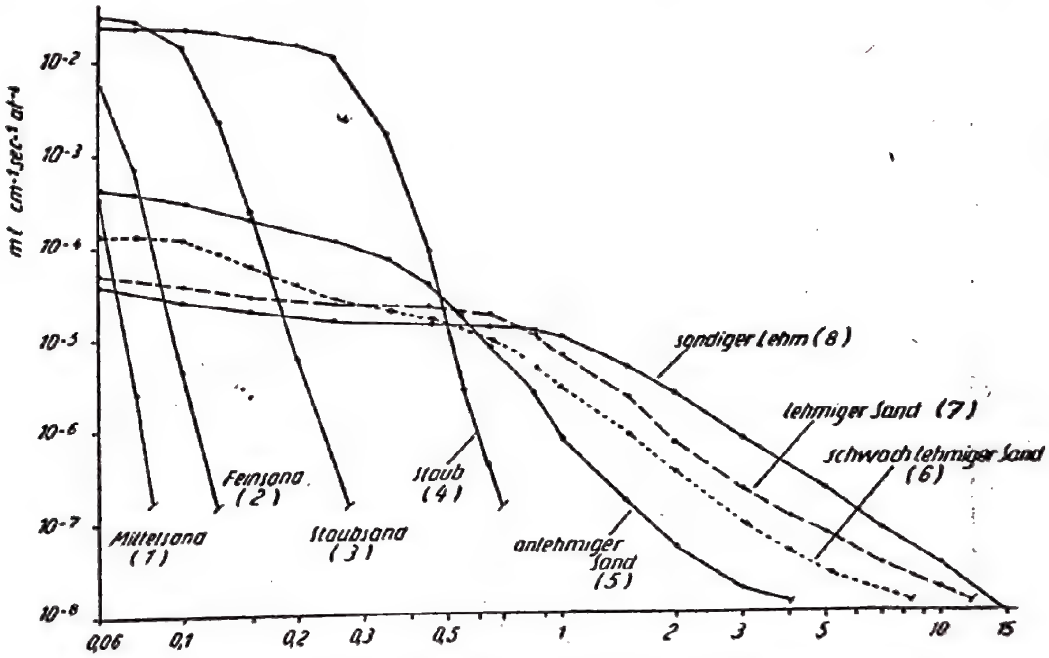

Abb. 6. Kapillare Leitfähigkeit von Sand- und Lehmböden.

Sanden einen anlehmigen bis lehmigen Charakter verleiht, vermag die kapillaren Wasserleitfähigkeitsverhältnisse wesentlich zu verändern: Einer um Grössenordnungen geringeren kapillaren Leitfähigkeit gegenüber tonarmen Sanden bei geringen Saugspannungen folgt eine sich über einen grösseren Saugspannungsbereich erstreckende allmähliche Verringerung der kapillaren Wasserleitfähigkeit, die nicht mehr den Charakter eines scharf umgrenzten Kapillarrissbereiches trägt. Zwischen lehmigen Sanden und Lehmen

bestehen gleitende Übergänge. Während bei geringen Saugspannungen mit zunehmendem Silt- und Tongehalt die kapillaren Wasserleitfähigkeiten absinken, kehren sich bei hohen Saugspannungswerten die Verhältnisse um. In anlehmigen und lehmigen Sanden kommt die kapillare Wasserbewegung schon vor Erreichung des Welkepunktes zum Stillstand. Obgleich die Übergänge zwischen anlehmigen Sanden und Lehmen gleitend sind, heben sich trotzdem anlehmige bis lehmige Sande deutlich durch ihre höheren Wasserleitfähigkeiten bei geringen Saugspannungen und ihre geringeren Wasserleitfähigkeiten bei höheren Saugspannungen gegenüber Lehm- und Tonböden ab. Sie können daher als eine besondere Gruppe aufgefasst werden.

Demgegenüber sind die Unterschiede zwischen sandigen Lehmen, tonigen Lehmen und Tonen gering, und zwar im gesamten Bereich des pflanzenverfügbaren Wassers (Abb. 7). Während bis zu Saugspannungswerten von etwa 1 at die kapillare Leitfähigkeit sich nur relativ wenig ändert, setzt von diesem Bereich an eine merkliche kontinuierliche Verringerung um etwa drei Zehnerpotenzen ein. Die kapillaren Wasserleitfähigkeiten liegen in Lehm- und Tonböden bei geringen Saugspannungen etwa um 10^{-5} ml cm^{-1} s^{-1} at^{-1} und sinken zwischen 10—15 at auf Werte zwischen 10^{-7} und 10^{-8} ml

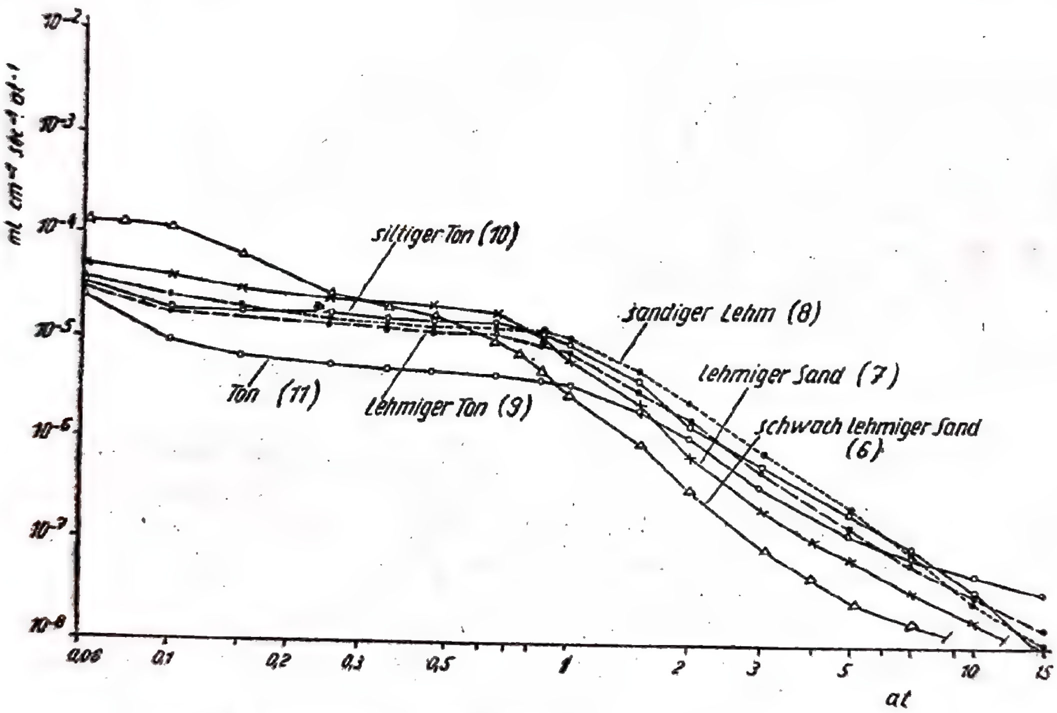

Abb. 7. Kapillare Leitfähigkeit von Lehm und Tonböden.

cm^{-1} s^{-1} at^{-1} ab. Auch diese Lehm- und Tonböden können zu einer besonderen Gruppe zusammengefasst werden.

Wie die Ergebnisse unserer Messung zeigen, erscheint es sinnvoll, als eine weitere besondere Gruppe die Staublehme und Siltböden zusammenzufassen (Abb. 8). Diese Gruppe weist gegenüber normalen Lehmen und Tonen bis zu Saugspannungswerten von etwa 1 at um etwa eine Grössenordnung höhere kapillare Wasserleitfähigkeiten auf. Zwischen 1—3 at setzt jedoch

ein steiler Abfall der kapillaren Wasserbewegung ein, der den Charakter eines Kapillarrissbereiches hat. Trotzdem hört im Gegensatz zu den tonarmen Sanden die kapillare Wasserbewegung nach dem Kapillarrissbereich nicht völlig auf, sondern erstreckt sich mit Werten, die den Lehm- und Tonböden nahe kommen, bis zu dem 15-at-Punkt. Infolgedessen liegen alle untersuchten

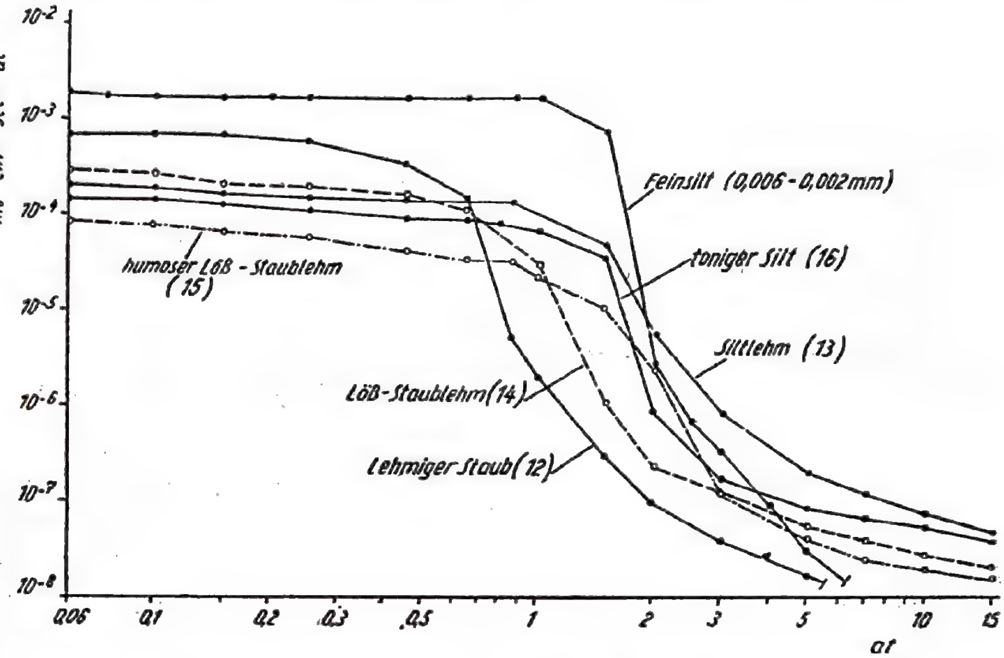

Abb. 8. Kapillare Leitfähigkeit von Staub- und Schluff-(Silt)-böden.

Lehm-, Ton- und Siltböden bei Saugspannungswerten von 10—15 at mit ähnlich geringen Werten der kapillaren Wasserleitfähigkeit zwischen 10^{-8} und 10^{-7} ml cm^{-1} s^{-1} at^{-1}.

Wenn wir eine Gliederung verschiedenartiger Böden nach ihrer Korngrössenzusammensetzung in Abhängigkeit von ihrer kapillaren Wasserleitfähigkeit vornehmen wollen, so lassen sich auf Grund der Untersuchungsbefunde folgende 4 Gruppen unterscheiden:

1) ton- und siltarme Sande,
2) anlehmige bis lehmige Sande,
3) Lehme und Tone,
4) Staub- und Schluff-(Silt-)böden.

Es sei besonders darauf hingewiesen, dass in den Abb. 6—8 logarithmische Koordinaten vorliegen, und es besteht die Frage, ob bei einer solchen Darstellungsweise ein irreführendes Bild vermittelt wird (Richards und Wadleigh, 1952, S. 81). Tatsächlich ist es so, dass in den meisten Böden schon bei geringen Saugspannungswerten ein steiler Abfall der kapillaren Wasserbewegung erfolgt (Abb. 9, in der eine lineare Koordinateneinteilung gewählt wurde) und — ausser dem Siltlehm (13) — bereits von 0,6 bis 0,8 at aufwärts absolut sehr geringe Werte der kapillaren Leitfähigkeit von weniger als 10^{-5} cm. cm^{-1} s^{-1} at^{-1} vorliegen. Bei Wahl eines grösseren Maßstabes

(s. Abb. 9, rechts) sehen wir jedoch, dass auch bei höheren Saugspannungswerten starke Veränderungen der kapillaren Wasserleitfähigkeit und absolut hohe Unterschiede von einer Grössenordnung zwischen verschiedenen Böden vorhanden sind. Es erhebt sich daher die Frage, wo die für das Pflanzen-

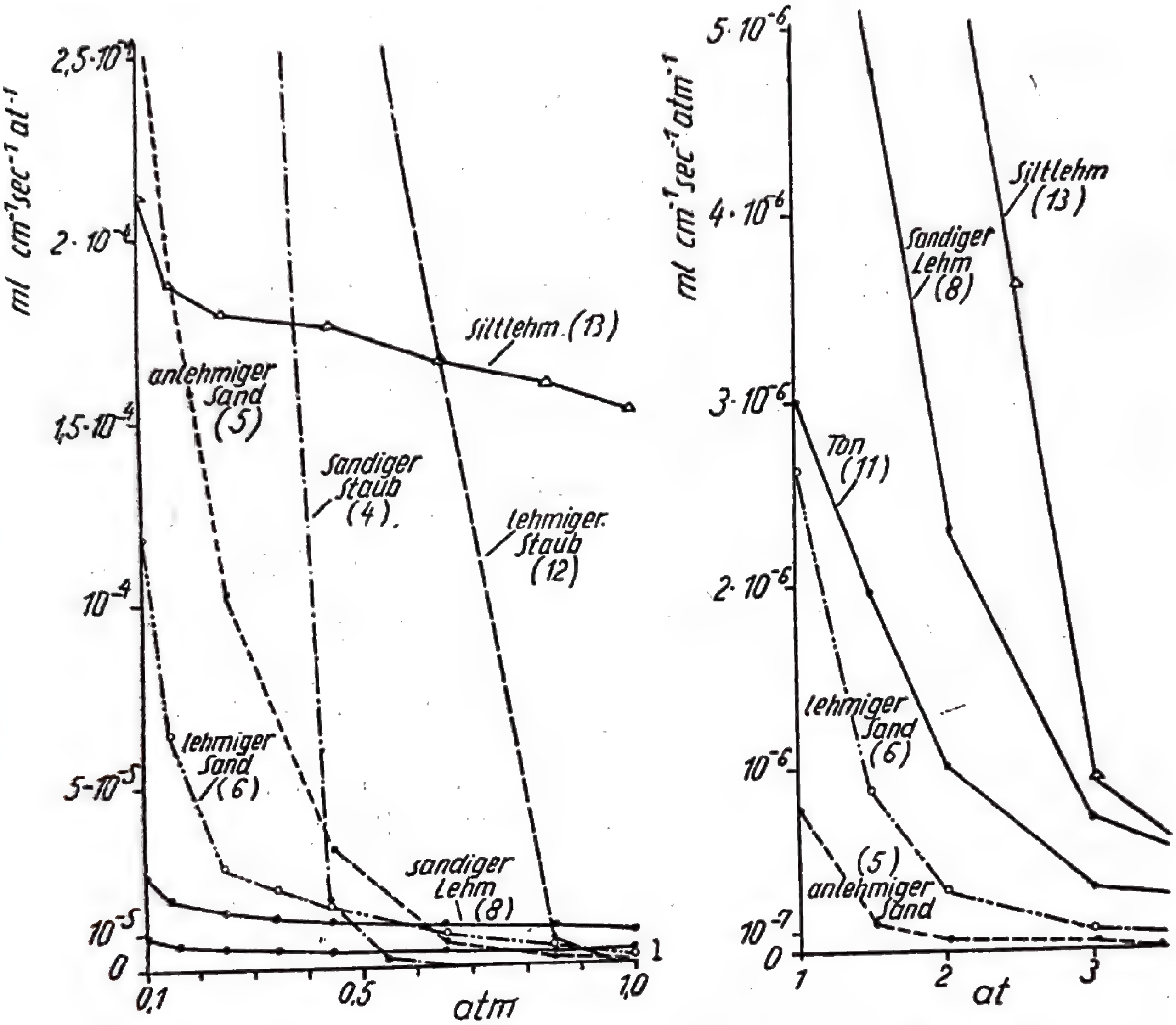

Abb. 9. Kapillare Leitfähigkeit in verschiedenen Böden bei linearer Koordinatenteilung.

wachstum wichtige untere Grenze der kapillaren Leitfähigkeit liegt. Diese Frage ist schwer zu beantworten und kann nur annähernd abgeschätzt werden, da unter anderem die jeweils wirksamen Saugspannungsgradienten und die Feuchtigkeits- und Wurzelverteilung unter natürlichen Bodenbedingungen sehr verschieden sein können. Bei einer Analyse der Verteilung der Saugspannungswerte in verschiedenartigen Böden bei sommerlicher Austrocknung (Vetterlein, 1964 b) hat sich ergeben, dass an der unteren Grenze der durchwurzelten Schicht mit Saugspannungsgradienten von etwa 1,0—0,1 at pro cm in vertikaler Richtung gerechnet werden kann. In unmittelbarer Wurzelnähe können wahrscheinlich auch weitaus höhere Gradienten über

kürzere Strecken auftreten. Wenn wir weiterhin als Durchschnittswert der unteren Grenze des für die pflanzliche Produktion notwendigen Wasserverbrauches einen Wert von 2 mm pro Tag veranschlagen, dann gibt der bewachsene Boden 0,2 ml cm^{-2} Tag^{-1} ab, die der durchwurzelten Schicht durch kapillare Wasserleitung aus grösseren Tiefen zugeführt werden müssen. Beträgt der Saugspannungsgradient an der unteren Grenze der durchwurzelten Schicht 1 at cm^{-1}, so wird die geforderte Wassermenge transportiert, wenn die kapillare Leitfähigkeit $2.3 \cdot 10^{-6}$ ml cm^{-1} s^{-1} at^{-1} beträgt. Dieser Wert aber ist in den meisten Lehm-, Ton- und Siltböden in dem Saugspannungsbereich von 1—3 at erreicht, in Sandböden jedoch schon bei weitaus geringeren Saugspannungswerten von etwa 0,1—0,3 at. In Siltböden fällt diese „kritische Grenze" etwa mit dem Kapillarrissbereich zusammen. Es muss jedoch berücksichtigt werden, dass entsprechend den jeweiligen Verhältnissen diese kritische Grenze um etwa eine Zehnerpotenz höher oder niedriger liegen kann.

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ZUSAMMENFASSUNG

Es werden Ergebnisse von Bestimmungen der kapillaren Wasserleitfähigkeit an verschiedenartigen Böden und an homodispersen Kornfraktionen nach einem Durchflussverfahren im gesamten Bereich des pflanzenverfügbaren Wassers mitgeteilt. In allen homodispersen Kornfraktionen und in tonarmen Sanden lässt sich ein scharfumgrenzter Kapillarrisspunkt erkennen, der mit bekannten Kapillaritätsgesetzen erklärbar ist. In allen untersuchten Lehm- und Tonböden ist ein scharf umgrenzter Kapillarrissbereich nicht nachweisbar.

Dagegen liegt in Staublehmen und Siltböden ein weniger scharf umgrenzter Kapillarrissbereich zwischen etwa 1—3 at.

Hinsichtlich der kapillaren Wasserbewegung kann folgende Gliederung der Böden vorgenommen werden:

1) ton- und siltarme Sande,
2) anlehmige bis lehmige Sande,
3) Lehme und Tone,
4) Staub- und Schluff- (Silt-) böden.

Der für die Wasserversorgung der Pflanzen auf kapillarem Wege kritische Wert der kapillaren Wasserbewegung fällt in den meisten Lehm-, Ton- und Siltböden etwa in den Saugspannungsbereich von 1—3 at.

SUMMARY

Results of investigations on capillary water conductivity in different soil samples and homodispersed quartz separates by means of flowing through methods in the whole range of the available moisture content are reviewed. In all homodispersed quartz separates and in clayless sands a sharply expressed point of capillary connection rupture may be detected, which can be explaned through capillarity laws. On all investigated clays and loams such a sharply expressed point is not demonstrable. On the contrary, in silt loams and silts a less sharply expressed point of rupture is visible ranging from 1 to 3 atmospheres.

Concerning capillary water movement, the following soil classification may be presented:

1) sands of low clay and silt content,
2) light loamy sands to loamy sands,
3) loams and clays,
4) silt soils.

As regards water supply of plants through capillary flow the critical value of capillary water movement lies in most loams, clays and silty soils in the range of soil moisture suction about 1 to 3 atmospheres.

RÉSUMÉ

On présente des résultats de déterminations sur la conductibilité capillaire dans des sols de nature différente et des fractions de quartz à diamètre homogène, suivant la méthode de percolation capillaire dans tout le domaine entier de l'eau accessible aux plantes. Dans toutes les fractions de quartz et dans les sables sans argile on peut reconnaître un point de rupture capillaire nettement circonscrit, explicable par des lois de capillarité bien connues. On ne peut prouver dans tous les sols de limon ou d'argile examinés l'existence d'un domaine de rupture capillaire nettement circonscrit. Dans les limons poudreux et les sols silteux, un domaine de rupture capillaire moins nettement circonscrit se trouve entre 1 et 3 atm.

En ce qui concerne le mouvement capillaire de l'eau, on peut établir le groupement suivant des sols:

1. Sables pauvres en argile et en limon;
2. Sables légèrement limoneux jusqu'à limoneux;
3. Limons et argiles;
4. Sols poudreux et silteux.

La valeur critique du mouvement capillaire de l'eau pour l'approvisionnement en eau des plantes (par voie capillaire) se situe dans la plupart des sols limoneux, argileux et silteux environ dans le domaine de la force de succion de 1 à 3 atm.

DISCUSSION

H. LEHR (Rumänische Volksrepublik). Bezugnehmend auf die in der heutigen Nachmittagssitzung vorgebrachten Mitteilungen über die Probleme des Durchflusses poröser Medien, möchte ich einige Bemerkungen zu den hier von den Herren Kirkham, Kutilek, Gardner und Vetterlein angegebenen Methoden, über die quantitative Bestimmung der Durchflusswassermenge machen. Es ist gerade das Gebiet der Sickerwasserströmung, in dem wir Bauingenieure am nächsten mit unseren Kollegen von der Bodenkultur zusammenarbeiten sollen, denn die Wirtschaftlichkeit jedes Meliorationsprojektes ist im weiten Masse von der Wahl des Querschnittes der Entwässerungsgräben, ihrer Entfernung und vom Querschnitt der Eindeichungen bestimmt. Um einerseits die Abmessungen der Erdbauten in den von dem zulässigen Sicherheitsgrad geforderten Mindestgrenzen zu halten, andererseits aber die Wirksamkeit der Bewässerung und Entwässerung durch die getroffenen baulichen Massnahmen zu gewährleisten, ist es notwendig, den Durchflussprozess in allen seinen Einzelheiten genau zu studieren. Leider ist dieses Grenzgebiet, in der sich Hydraulik, Bodenmechanik, Bodenphysik, Bauingenieurwesen und Bodenkultur begegnen, von den verschiedenen Vertretern dieser Wissenszweige zu einseitig und nur von ihrem Standpunkt behandelt, während man die anderen übernommenen Formeln und Buchungsmethoden oft kritiklos übernimmt. Dies ist wohl der Grund, dass in den meisten Fällen die Ergebnisse der Rechnungen mit den Beobachtungen nicht übereinstimmen und dass man die Bemessung von Anlagen, die die Senkung des Grundwasserspiegels zum Zwecke haben oder die Anreicherung des Wassergehaltes im Boden bewirken sollen, auf Grund von Erfahrungstatsachen oder auf Grund von grossangelegten Versuchen an Ort und Stelle vornimmt.

Alle die Berechnungsformeln sind von der Potentialtheorie abgeleitet und haben wohl mehr der Entwicklung der Funktionstheorie einer komplexen Veränderlichkeit als der wirklichen Erfassung des physikalischen Phänomens gedient. Sehr folgerichtig haben mehrere hier vorgebrachte Arbeiten auf die Wichtigkeit der Struktur des Bodens, des Adsorptionskomplexes und anderer physikalischen Grössen für die Erfassung des Durchflussvorganges hingewiesen. Ich möchte hier auf die von mir im Rahmen der wissenschaftlichen Tagung des Institutes für Bauwesen Bukarest vorgetragenen Arbeiten hinweisen. Hier wird die Idee dargelegt, die Flüssigkeitsbewegung in porösen Medien auf Grund der für ein Kontinuum geltenden Rechenmethoden (wie Gradientenbildung, Divergenz usw.) zu verlassen und die Betrachtung auf ein inhomogenes, mehrphasiges, disperses System auszudehnen. In diesem Falle werden die infolge der Wechselwirkungen zwischen den einzelnen Phasen wirkenden Kräfte auf Grund der Grenzschichttheorie ermittelt und auf diese Weise die Bewegung der viskosen Flüssigkeit, in der das Porenwasser erscheint, bestimmt. Auf diese Art erhält man auch die auf die einzelnen Korngrössen vom Durchfluss des Wassers ausgeübten Pressionskräfte.

Auf Grund dieser Betrachtungsart ist man imstande, von einigen rein mechanistischen Vorstellungen Abstand zu nehmen wie die der dynamischen Kräfte des Sickerwassers als Differenz von den hydrostatischen Drucken $F=\gamma w \cdot^{2}$, dem Porenwasserdruck, als Anteil des vom Wasser übernommenen Anteiles der äusseren Krafteinwirkung, der kapillaren Steighöhe in Tonböden, die sich theoretisch bis zu 50—100 m ergibt, die aber keiner physikalischen Wirklichkeit entsprechen. Ebenso kann diese Betrachtungsweise eine bessere Erfassung der rheologischen Eigenschaften der Bodenarten in Funktion ihres Wassergehaltes ermöglichen, und so eine einwandfreie Erfassung des Zusammenhanges zwischen Wasserbewegung und Volumänderung und Pressionsbeständigkeit. Ich benütze die Gelegenheit, um die hochqualifizierten Verfasser der Beiträge zur 1. und 6. Kommission auf diese Seite des Problems hinzuweisen und auf diese Art eine engere Zusammenarbeit zwischen den Forschern auf dem Gebiet der Bodenphysik und denen, die sich mit baulichen Problemen der Bodenmechanik beschäftigen, zu ermöglichen, damit in den internationalen Kongressen und Tagungen auch diese Fragen erörtert werden.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 10

L'ÉTUDE DES RÉGIMES D'HUMIDITÉ DES SOLS POUR DES BUTS ÉCOLOGIQUES. LES INDICES D'HUMIDITÉ ACTIVE

CONST. D. CHIRIȚĂ [1]

Le régime d'humidité du sol présente une importance de premier ordre pour la vie des plantes, la répartition géographique des différentes espèces et associations végétales naturelles et la production végétale. Par conséquent l'écologie végétale, la géobotanique, l'agriculture et la sylviculture sont directement interessées à la connaissance de ce régime.

Le régime de l'eau dans le sol — tel qu'il avait été défini pour la première fois par Vysotzki (1934), et récemment par Rode (1956), doit être considéré comme un complexe des régimes suivants: le régime d'approvisionnement du sol en eau de différentes sources, le régime du mouvement de l'eau dans le profil de sol et dans son substratum lithologique et le régime de l'état de saturation en eau du sol. Ces considérations nous ont conduit à la distinction des notions de régime hydrologique et de régime d'humidité comme constituantes de celle de régime de l'eau dans le sol (Chiriță, 1961).

Du point de vue écologique l'importance principale revient au régime d'humidité du sol, qui — toutefois — ne peut être conçu et expliqué que de cause à effet, lié au régime hydrologique (le régime d'approvisionnement du sol en eau de différentes sources et le régime de la circulation de l'eau dans le sol et le substratum lithologique). L'étude du régime d'humidité du sol présente des difficultés spéciales, car dans le même profil de sol, le taux de saturation en eau marque une double variation: l'une en fonction du temps et l'autre en fonction de l'espace (d'un niveau à l'autre du profil de sol).

L'étude de ce régime pour des buts écologiques doit mettre en évidence ces deux variations, au moins pendant la saison de végétation et — en même temps — exprimer l'humidité du sol d'une manière indicatrice pour l'approvisionnement en eau des plantes.

La méthodologie de l'étude et les manières d'expression du régime d'humidité du sol sont bien connues. On doit aussi remarquer l'expression moderne énergétique de l'humidité comme valeur de la tension de l'eau ou de la succion (Marshall, 1959; Richards, 1960). Un ouvrage spécial de méthodologie de l'étude du régime de l'eau dans le sol a été élaboré récemment par Rode (1960). D'importantes contributions dans ce domaine

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sont dues aussi à l'école pédologique d'Eberswalde (Prof. E. Ehwald), surtout celles de Vetterlein.

Dans ce rapport, on présente une manière d'étude du régime d'humidité du sol, correspondant aux exigences de l'écologie végétale, en considérant ce régime comme régime des conditions d'approvisionnement en eau des plantes. Dans cette acception, l'étude du régime d'humidité du sol a comme but de faire connaître les variations en fonction du temps et le long du profil de sol, de l'accessibilité de l'eau pour les plantes et les réserves d'eau accessibles.

L'importance de l'accessibilité de l'eau pour les plantes entre la capacité au champ et le coefficient de flétrissement a formé l'objet de nombreuses recherches expérimentales ; la majorité de ces recherches, l'étude de synthèse dûe à Richards et Wadleigh (1952) et l'examen critique des conclusions des divers travaux fait récemment par Hagan et Vaadia (1960), confirment le caractère différent de l'accessibilité de l'eau entre les deux limites mentionnées ci-dessus et, par conséquent, la dépendance des croissances végétatives et du niveau des récoltes — dans certaines conditions de milieu et de culture — du degré de cette accessibilité.

L'accessibilité de l'eau du sol pour les plantes est déterminée — dans les sols nonsalinisés — par la tension avec laquelle l'eau est retenue par les phases solides du sol, ainsi que par la possibilité de développement et la densité du système radiculaire des plantes. Ainsi, l'étude du régime d'humidité du sol pour des buts écologiques doit faire appel à la détermination de la succion („matric suction", Marshall (1959), Richards, (1960)) de l'eau dans le sol. D'après Richards et Wadleigh (1952), les indices moyens de la tension de l'humidité obtenus pour une couche de sol assez épaisse peuvent représenter d'une manière satisfaisante les conditions d'humidité du sol dans le milieu proche des racines, pour la couche entière ou une partie de celle-ci.

L'étude du régime d'humidité du sol dans cette conception comporte l'établissement des courbes succion-humidité (courbes de rétention) pour les différents niveaux du profil de sol et du substratum étudié, la détermination de la variation de l'humidité du sol (exprimée en pourcentages volumétriques), la transformation des valeurs d'humidité en valeurs de succion et l'établissement des chronoisoplètes de succion.

L'application de ce procédé nécessitant des déterminations de succion est limitée aux laboratoires possédant les appareils nécessaires à ce but. Cette limitation oblige à l'utilisation d'un procédé indirect, accessible à toutes les unités de recherches, et qui fasse possible l'étude du régime d'humidité d'une manière suffisamment indicatrice de l'accessibilité de l'eau pour les plantes et donc de la succion, sans exécuter des déterminations courantes de succion.

Ainsi, pour l'expression de l'humidité du sol, nous utilisons ***le taux de saturation du sol en eau accessible***, nommé de manière conventionelle l'indice élémentaire d'humidité active du sol I_e (Chiriță, 1962), donné par le relation

$$I_e = \frac{H - CF}{C_{EA}} 100,$$

où
H est humidité du sol exprimée en g/100 cm³ de sol,
CF — coefficient de flétrissement,
C_{EA} — capacité en eau accessible (entre les limites CC — capacité au champ ou la teneur en eau à la succion correspondante, et CF — quantité d'eau existante pour une succion de 15 atm.

La valeur de l'indice d'humidité proposé est zéro au coefficient de flétrissement CF, 100 à la capacité au champ CC, < 0 aux humidités $< CF$ et $>$ 100 aux humidités $> CC$.

Cet indice est considéré par Rode (1960) comme étant l'expression la plus suggestive de l'humidité du sol par rapport à l'approvisionnement en eau des plantes. Mitchourine (1959) a étudié la transpiration de certaines plantes de culture en fonction d'une indice analogue.

À la série des valeurs possibles de l'indice d'humidité active utilisé par nous correspond la gamme des valeurs de la succion de 0 à 15 et $>$ 15 atm.

Pour les buts écologiques, on peut se limiter à la connaissance généralisée des valeurs de la succion, en utilisant des intervalles — désignés par symboles — d'importance significative pour la physiologie des plantes, auxquels, pour les sols à texture moyenne, correspondent les catégories d'indices élémentaires indiqués ci-dessous :

I — indices < 0, eau inaccessible et très difficilement accessible aux plantes ;
A_1 — indices 0—20, eau difficilement accessible (succions de 15 à 8 atm.) ; conditions de végetation très difficiles, près de l'apparition et l'apparition même du processus de flétrissement ;
A_2 — indices 20—50, eau à accessibilité relativement difficile (succions de 8 à 1 atm.) ; développement des plantes freiné ;
A_3 — indices 50—90, eau facilement accessible ;
A_3^+ — indices 90—100, eau facilement accessible, humidité proche de la CC ;
E — indices $>$ 100, eau facilement accessible, humidité CC.

L'intervalle E peut être sous-divisé en E_1, E_2, E_3, E_4 selon *)
E_1 — humidité entre CC et Ccp *) ;
E_2 — humidité entre Ccp et CM **) ;
E_3 — submersion partielle du sol ;
E_4 — submersion complète du sol.

La figure 1 présente la courbe humidité-succion, les intervalles mentionnés ci-dessus et les valeurs limites correspondantes des indices d'humidité active pour un sol à texture moyenne. Les indices limites 20 et 50 des intervalles A_1 et A_2 de la succion diminuent pour les sols à texture plus grossière par rapport aux sols à texture limoneuse (limono-sableuse, sablo-limoneuse et,

*) Ccp — capacité en eau capillaire.
**) CM — capacité en eau maxima.

sableuse), devenant approximativement 10, 7, 5, respectivement 40, 30, 20; pour les sols à texture plus fine que la texture limoneuse, ces valeurs changent aussi, en augmentant.

La connaissance des intervalles de succion correspondants aux diverses valeurs de l'indice d'humidité active satisfait les exigences minimes de l'écologie concernant l'accessibilité de l'eau pour les plantes.

Les intervalles indices d'humidité-succion mentionnés ci-dessus correspondent d'une manière satisfaisante aux domaines d'humidité caractéristiques pour les groupes de plantes xérophytes, xéromésophytes, mésophytes, mésohygrophytes, hygrophytes et ultrahygrophytes.

La figure 2 montre la manière de représentation graphique du régime d'humidité pour un chernozem modérément lévigué sur loess de la sylvosteppe, à l'aide de l'indice élémentaire d'humidité active. On indique aussi les réserves d'eau accessible en mm. jusqu'à des profondeurs de 0,5 m, 1 m et 2 m. La figure 3 présente le même cas, mais d'une manière généralisée; au lieu des valeurs des indices élémentaires d'humidité active on a utilisé les intervalles humidité-succion proposés. L'aspect est simplifié, plus expressif et suffisamment indicateur pour les buts de l'écologie.

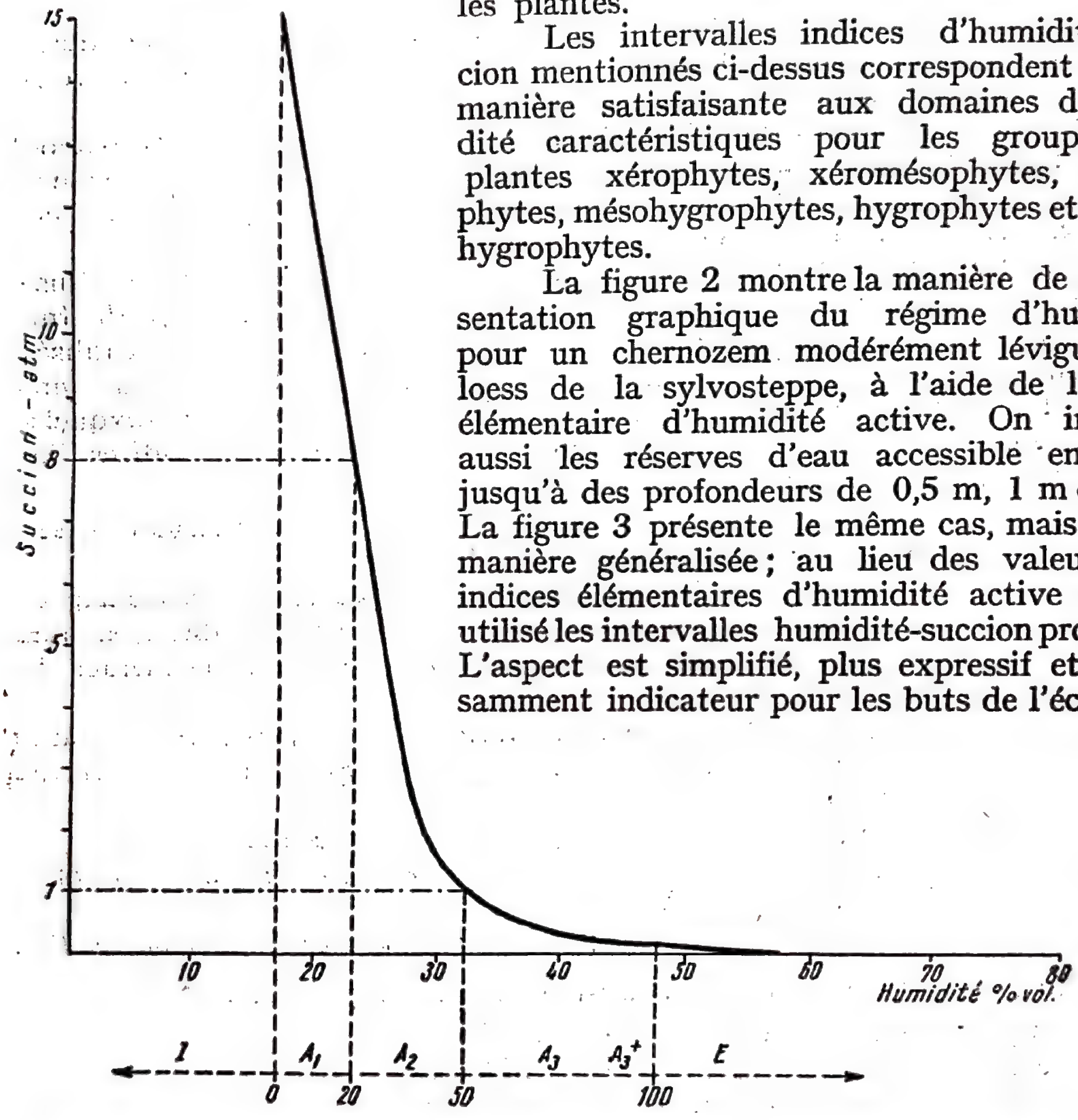

Fig. 1. Courbe humidité-succion d'un sol limoneux (avec l'intervalle de l'humidité active et des indices I_e délimitant les intervalles I, A_1, A_2, A_3, A_3, E).

Horizons et profils d'humidité. La zone du profil de sol dont les valeurs de l'indice d'humidité sont comprises dans la même catégorie (I, A_1, A_2 etc.) est considérée comme un „horizon d'humidité" et est exprimée par le symbole de la catégorie respective. La totalité de ces horizons dans le profil de sol constitue „le profil d'humidité" ou „le profil hydrique du sol". On peut

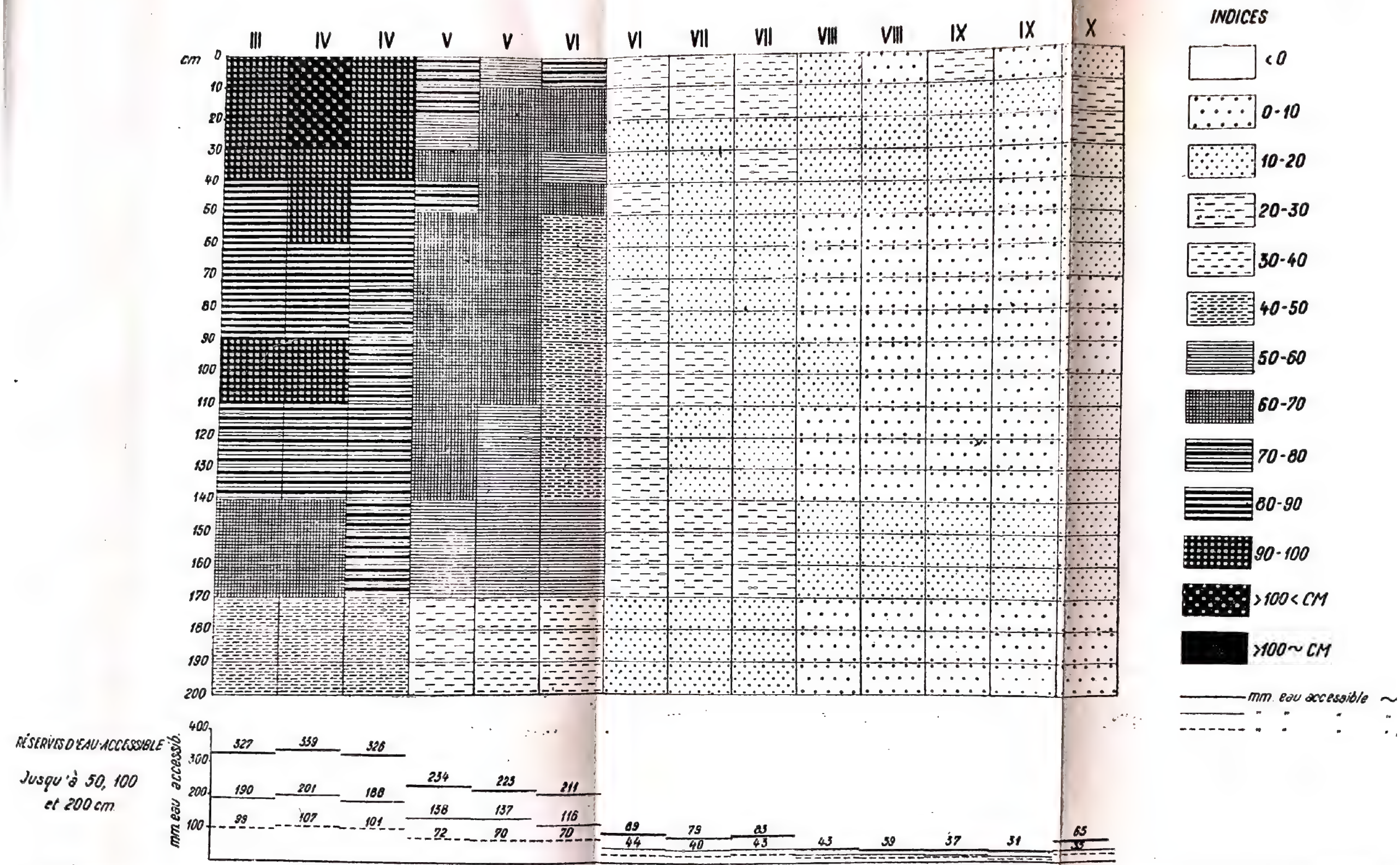

Fig. 2. Expression du régime d'humidité du sol par des indices élémentaires d'humidité active et des réserves d'eau accesible. (Chernozem lévigué de forêt-steppe, sous une forêt de *Quercus pedunculiflora*). Lel Région de Bucarest.

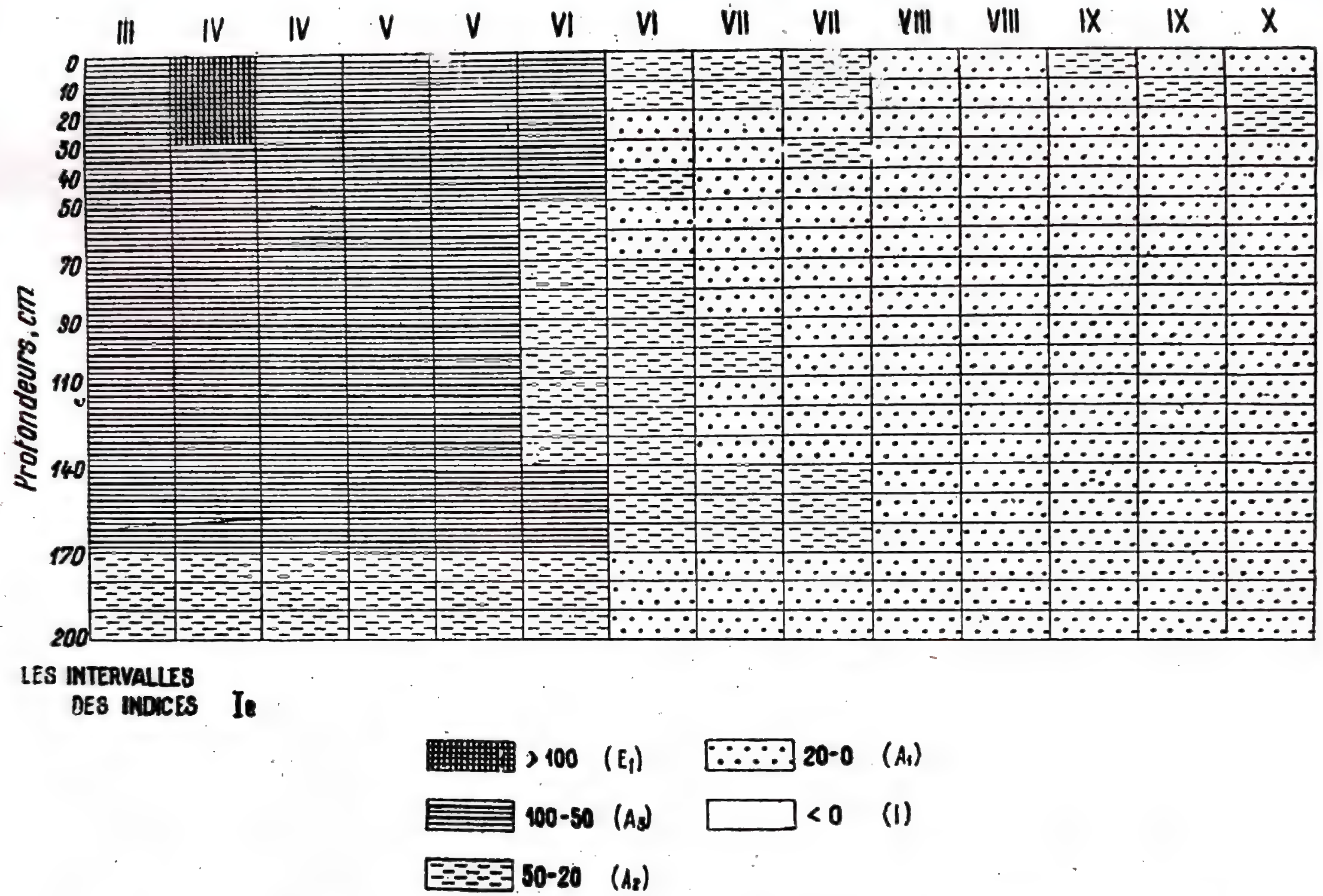

Fig. 3. Expression généralisée du régime d'humidité par les intervalles de indices (cas de la fig.2).

Tableau

Indices d'humidité active et principaux profils

Nr.	Sols	Indices d'humidité		
		I_{mv}	I_p	I_{es}
1	Chernozem calcaire	50	44/15	14/14
2	Chernozem à nappe phréatique	72	77/91	41/81
3	Chernozem lévigué	61	72/50	15/10
4	Chernozem lévigué de dépression	67	75/96	47/89
5	Chernozem lévigué à nappe phréatique	92	73/107	48/93
6	Sol brun-roux de forêt	63	73/73	42/49
7	Sol podzolisé à pseudogley, de dépression	86	114/118	43/84
8	Sol podzolisé brun à pseudogley	110	108/81	102/75
9	Sol amphigleyique	112	125/110	122/122
10	Sol podzolique de terrasse à pseudogley	107	131/79	23/10
11	Sol brun de forêt, de montagne	99*	102	100
12	Sol brun de forêt, de montagne à pseudogley	118*	130/93	99/370

* Indice médian de la saison de végétation.
** Les symboles en ( ) désignent une couche de sol mince, de 10—15 cm d'épaisseur.

donc exprimer le profil hydrique du sol d'une manière analogue à celle utilisée pour désigner les profils des types génétiques de sol. Par exemple l'expression $A_1A_2/A_3A_2A_1$ représente l'humidité des horizons humifères $A + AC$/ l'humidité des horizons $C_{ca} + C$ d'un sol chernozémique à un moment donné. Le régime d'humidité du sol peut être exprimé par une suite de profils d'humidité établis aux moments caractéristiques de la saison de végétation.

Indices moyens d'humidité active à un moment donné. Ce sont les moyennes des indices élémentaires déterminés pour la zone humifère intensément utilisée par les racines des plantes — la zone R, ainsi que pour l'horizon suivant — la partie supérieure de la couche minérale sousjacente.

L'indice printanier I_p et I'_p et *l'indice estival I_{es}* et I'_{es} (caractéristiques pour les deux zones de sol déjà citées). Dans certains cas, par exemple pour les cultures agricoles d'automne, il est nécessaire de calculer aussi l'indice d'humidité automnal I_t.

L'indice médian de la saison de végétation. Cet indice médian exprime pour la zone R du profil de sol l'humidité moyenne de la période optimale de la saison de végétation (par exemple les mois de Mai, Juin et la première moitié de Juillet).

L'indice moyen de la saison de végétation (I_{mv}) exprime pour la zone R du profil de sol la moyenne des indices mensuels au long de cete saison.

Indices de relation. Pour la différenciation plus expressive du régime d'humidité des sols on a constaté l'utilité de l'emploi des indices de relation suivants: I_{vs} — indice de variation saisonnière $= I_p/I_{es}$: I'_p/I'_{es}; I_{rp} et I_r, indices moyens de répartition de l'humidité dans le profil de sol: $I_{rp} = I_p/I'_p$ et $I_{res} = I_{es}/I'_{es}$.

7
d'humidité de certains sols de la R.P.Rumaine

Indices de relation			Principaux profils d'humidité			
I_{vs}	I_{rp}	I_{res}	Au début de la saison de végétation	Après la sécheresse de printemps	Après les pluies de Mai—Juin	Vers la fin de la saison de végétation
3,14	2,93	1	A_3/A_1	$(I)A_1A_2/A_1$	A_3A_2/A_2A_1	$(I)A_1/A_1(I)$**
1,88	0,85	0,5	$E_1(A_3^+)/A_3A_2{}^*E_1$	$A_2A_3/A_3A_2^+$	$A_3A_3/A_3^+E_1$	$A_1A_2/A_3A_3^+E_1$
4,8	1,45	1,5	$A_3^+A_3(A_2)$	A_3/A_3A_2	A_3/A_2	A_1/A_1
1,60	0,78	0,53	$A_3^+E_1/E_1$	A_2A_3/A_3	A_3E_1/E_1	$(I)A_2A_3/A_3$
1,52	0,68	0,52	$A_3^+E_1/E_1$	$A_3^+/A_3^+E_1$	$A_3^+E_1/E_1$	A_1A_2/A_3E_1
1,74	1,0	0,86	$A_3^+/A_2A_3^+$	A_2A_3/A_3	$A_3^+/A_3A_3^+$	A_1A_2/A_2A_3
2,7	0,97	0,51	$E_1A_3/E_1E_2E_1A_3$	$A_2A_3/E_1E_2E_1A_3$	$E_1/E_1E_2E_1A_3$	A_1A_2/A_3
1,0	1,33	1,36	$E_1/A_2A_3^+$	$(A_3)E_1/E_1)A_3$	E_1E_2/A_3	$(A_3)E_1/A_3$
1,0	1,14	1	$E_1E_2/A_3^+E_1E_2$	$E_2E_1A_3/A_3E_1E_2$	$E_1/E_1A_3E_1E_2$	$E_1A_3/A_3E_1(E_2)$
5,7	1,66	2,3	E_2/A_3	E_2E_1/E_1A_3	E_1/A_3	A_2A_3/IA_1
1	—	—	E_1A_3	E_1A_3	E_1A_3	$A_3^+(E_1)$
1,3	1,4	1,4	$E_1/A_3^+A_3E_1$	$E_1/A_3A_3^+$	$E_2E_1A^+$ $A_3A_3^+$	A_3/A_3

Le tableau 1 présente, pour certains principaux types de sol de Roumanie, les indices moyens d'humidité active et les indices de relation nécessaires pour caractériser le régime d'humidité, ainsi que les principaux profils d'humidité correspondants aux moments caractéristiques du régime climatique et du régime d'humidité des sols respectifs.

Les indices moyens d'humidité active et les indices de relation cités ci-dessus, calculés pour une période de 5—10 ans consécutifs, représentent un matériel important pour la classification des régimes d'humidité (classes, types, sous-types et variétés) d'après des critères quantitatifs, indicateurs pour des buts écologiques, agronomiques et sylvicoles. Un tel matériel nous a permis d'élaborer dans une première approximation la classification des régimes d'humidité des sols de Roumanie (Chiriţă, Butucelea, Măianu, Moţoc, 1964).

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RÉSUMÉ

Les valeurs de la succion dans le profil de sol au long de la saison de végétation sont considérées comme étant l'expression la plus adéquate du régime d'humidité du sol pour des buts écologiques. À cause des difficultés de determination de ces valeurs, on peut utiliser comme expression de l'humidité le taux de saturation du sol en eau accessible, un indice de l'humidité active dont les valeurs caractérisent certains intervalles de la gamme des succions.

On présente ces intervalles et les valeurs limite correspondantes des indices d'humidité active.

Pour caractériser et classifier les régimes d'humidité des sols on utilise des indices moyens saisonniers, determinés pour la zone radiculaire du profil de sol, des indices de relation exprimant le caractère de la variation saisonnière et de la répartition moyenne printanière et estivale de l'humidité dans le profil de sol et le substratum lithologique, ainsi que des „profils d'humidité" établis pour les moments caractéristiques de la saison de végétation.

SUMMARY

Suction values in the soil profiles during the vegetation season are considered as the most adequate expression of the soil moisture regime for ecological purposes. Owing to the difficulties to determine these values, one may utilise as an expression of soil moisture the soil saturation degree with available water an active moisture index, whose values characterize certain parts of the suction range. These intervals and the limit values corresponding to the active moisture indices are presented.

In order to classify the moisture regimes of the soils, seasonal average indices, determined for the radicular zone of the soil profile, relation indices expressing the character of seasonal variation and the spring and summer average moisture repartition in the soil profile and the lithologic substratum, as well as „moisture profiles", established for the characteristic moments of the vegetation season are utilized.

ZUSAMMENFASSUNG

Die Saugspannungswerte im Bodenprofil während der Vegetationsperiode werden als der angemessenste Ausdruck des Feuchtigkeitsregimes des Bodens für ökologische Zwecke betrachtet. Wegen der Schwierigkeit, diese Werte zu bestimmen, kann als Ausdruck der Feuchtigkeit die Sättigung des Bodens an aufnehmbarem Wasser verwendet werden, ein Index der aktiven Feuchtigkeit dessen Werte gewisse Intervalle der Saugspannungsskala kennzeichnen.

Es werden diese Intervalle und die ihnen entsprechenden Grenzwerte der Feuchtigkeitsindexe vorgelegt.

Um das Feuchtigkeitsregime der Böden zu charakterisieren und klassifizieren, werden jahreszeitliche für die Wurzelzone des Bodenprofils ermittelte Mittelindexe verwendet, sodann Relationsindexe, welche den Charakter der jahreszeitlichen Schwankungen und die durchschnittliche Verteilung der Feuchtigkeit im Bodenprofil und im lithologischen Untergrund ausdrücken, sowie „Feuchtigkeitsprofile", welche für die kennzeichnenden Zeitpunkte der Vegetationsperiode aufgestellt werden.

DISCUSSION

A. A. RODE (U.S.S.R.). Dr. Chiriță has presented a very interesting and fruitful scheme of moistening types and of water regimes of soils. It should be greatly appreciated that this scheme includes the problem of *water availability* the conception of hydrological soil horizons and the conception of soil hydrological profile. I should like to know in accordance to what data these horizons are distinguished — to current data or to the average annual ones?

C. D. CHIRIȚĂ. En concordance avec les données courantes.

A. A. RODE (U.S.S.R.). It means that hydrological horizons in soils may change their position in the profile.

C. D. CHIRIȚĂ. Il en est ainsi.

R. CĂDERE (République Populaire Roumaine) : La communication de Monsieur Chiriță acquiert une valeur particulière du fait que, en présentant les données pour une durée de 15 jours, elle permet l'enregistrement systématique de la présence des deux catégories de nappes phréatiques :

— nappes phréatiques saisonnières, si fréquentes dans de nombreuses zones de terres basses inondables et de plaines de la République Populaire Roumaine;

— nappes phréatiques pérmanentes.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

PECULIARITIES OF WATER-SALT REGIME IN THE SOILS OF WESTERN AND MIDDLE SIBERIA

N. V. ORLOVSKI[1]

The immense western and central Siberian territory, spreading from the Urals to the Lena river, is highly different from the analogous zones of the Russian plain, due to its bioclimatic and pedological conditions. As we advance eastwards, within the forest-steppe zones, the sum of hot season temperatures decreases from 2 600 to 1 500° C; the vegetation period falls from 190 to 140 days; the non-freezing period is reduced from 155 to 25 days; winters are colder and with less-abundant snows; the total annual rainfall decreases and the characteristic continental climate is becoming more pregnant. The same and even more marked differences occur in the steppe-zone too.

It is quite natural that such differences are influencing firstly the soils, which although they bear almost the same denominations within the whole of the respective zone, yet they differ from the analogous European zones by some genetic peculiarities and some characteristic traits concerning agriculture and forestry. All these bring a change in management systems as well as in soil reclamation methods and use of fertilizers.

The present report aims at establishing the peculiarities of the water and salt regime in the hydromorphic and semi-hydromorphic saline soils of Western and Middle Siberia as compared to the analogous European soils of the U.S.S.R.

Researches on this problem have so far been undertaken under the author's guidance, at the Ubinskoe reclamation experimental station, situated in Central Baraba (West Siberian Province), on the irrigation system in the Aley river basin, near Rubtzovsk a town in the Altay region (Prealtaisky Province) and in the Shira steppe of the Krasnoyarsk region (Minusinsk Province).

Concerning the conditions of Central Baraba with he slightly developed rolling relief peculiar to it, the scheme of the perched water table in a profile: ridge — swamp fringing belt — swamp, has been established, as shown in figure 1.

In spring, the thawing waters of the soloth depressions, covered by birch-tree groves where the soil is almost not frozen in winter under the thick

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snow layer, are intensely supplying the ground waters. Yet, their bulk runs off over the surface of the frozen chernozems, from the ridge down to the swamp, where it is slowly soaking through the rare thawed soil into the ground waters separated from the thawing ones by a thick, frozen and impermeable peat layer.

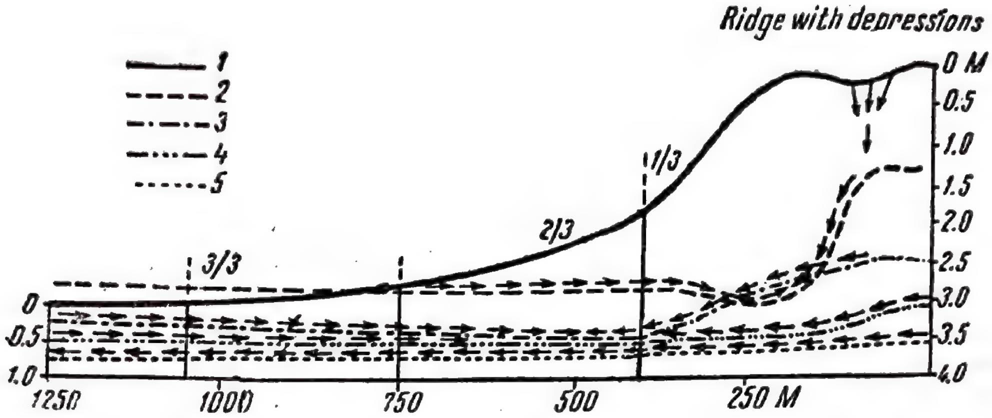

Fig. 1. Ground water level along the profile "ridge-swamp": *1.* — earth surface; *2.*—spring elvel; *3.* — summer level; *4.* — autumn-winter level; *5.* — autumn-winter level for a dry year.

Vegetation, which is rapidly developing in spring over the ridge, exhaustively uses the fresh water "vault" of the perched water table; in summer, the meadow vegetation from the swamp-fringed belt lowers the perched watertable level, conventionally called "depression". This is being slowly filled by the waters from the perched water-table, flowing downwards both from the ridge and the swamp. Due to evaporation on the spot, the stagnant waters are being concentrated and are the cause of the salinization process in the swamp-fringed belt. In dry years and only in autumn, the bog tallgrass, which is developing later, exhausts the summer side of the "depression" and the curve of the perched water table level enters the winter minimum period, according to the relief. When the drainage is improperly done, the "lens" of fresh thawing-waters, which are gathering each year as layers into the marsh, can be swiftly done away thus freeing the penetration of salt waters from the swamp-fringed belt.

The depth and speed of soil freezing depend on snow-layer thickness, soil moisture in autumn and level of ground waters (table 1). The meadow chernozem like soil over the ridge is freezing approximately to a depth of 150 cm; the depth of frozen layer is diminishing on the ridge slope, while in the swamp, peat is freezing only to a depth of 50—60 cm. Soils start freezing by the end of October — beginning of November, and thawing is starting in April. The thawing process ends in June and in the swamp even in July. Under drainage conditions, the peat frozen to a depth of 100 cm has not enough time to wholly thaw during the vegetation period. Thawing takes place only downwards, as under the conditions of the average annual air temperature of about 0°C the soil heat resources

under the frozen layer are not sufficient to exert a sensible influence on the inferior surface of the frozen layer.

Table 1

Average Data for Freezing and Thawing of Soils for 1942—1948 (according to Serebryanskaya, 1954).

Site	Freezing			Thawing		
	Max. aver. and absolute depth (cm)	rate (cm/day)	Total subzero air temperatures required for freezing of 1 cm of soil (°C)	rate (cm/day)	Total above-zero air temperatures required for thawing 1 cm. of soil (°C)	Freezing period (days)
Ridge, meadow-chernozem soil	147—185	0.90	—17.6	2.50	4.10	227
Slope of ridge, meadow solonchak	113—150	0.78	—25.0	2,70	2.10	192
Swamp-fringed belt, meadow-swamp solonchak soil	107—130	0.69	—25.2	1.78	5.10	217
Lowland sedge-reed swamp	67—100	0.38	—41.5	1.42	7.90	210
Upland sphagnous swamp	52—67	0.29	—49.0	1.00	11.70	206

Soil freezing is accompanied by an increase in the frozen layer moisture which takes place abruptly, at the boundary to the advancing frozen front, on account of absorption of a certain water quantity from the frozen layer below (table 2). If the ground water level is high and the frozen layer is

Table 2

Fluctuations in Soil Moisture in Winters of 1945 to 1949, according to Sokolovskaya

Site	Inflow of moisture (numerator, mm) for total frozen layer (denominator, cm)				Average diurnal moisture inflow (numerator, mm) ground-water table before snow-melting (denominator, cm)			
	1945—1946	1946—1947	1947—1948	1948—1949	1945—1946	1946—1947	1947—1948	1948—1949
Ridge, meadow-chernozem soil	—	$\frac{+41.4}{130}$	$\frac{+30.9}{120}$	$\frac{-3,5}{130}$	$\frac{-}{357}$	$\frac{+0.3}{270}$	$\frac{+0.2}{270}$	$\frac{0.0}{280}$
Slope of ridge, meadow solonchak	—	$\frac{+32.3}{120}$	$\frac{+37.1}{110}$	$\frac{+7.1}{120}$	$\frac{-}{292}$	$\frac{+0.2}{230}$	$\frac{+0.2}{250}$	$\frac{+0.1}{250}$
Swamp-fringed belt, meadow swamp solonchak soil	—	$\frac{+89.3}{80}$	$\frac{+61.3}{60}$	$\frac{+35.2}{110}$	$\frac{-}{310}$	$\frac{+0.6}{220}$	$\frac{+0.4}{230}$	$\frac{+0.2}{240}$
Lowland sedge-reed swamp	$\frac{+96.3}{40}$	$\frac{+15.8}{40}$	$\frac{+105.6}{40}$	$\frac{+85.0}{50}$	$\frac{+0.7}{230}$	$\frac{+0.1}{50}$	$\frac{+0.7}{110}$	$\frac{+0.6}{100}$

within the capillary fringe zone, this absorption is rapidly compensated on account of capillary supply while the ground waters are being consumed in transit for the freezing process of the soil water, fact which partially explains the winter minimum of the perched water table in the swamp (as in winter, there is no exhaustive use by vegetation and no evaporation). The more intensive the capillary supply, which increases as the level of the perched water table is developing downwards on the slope of the ridge, the bigger the volume of frozen water in the frozen soil.

The capillary supply intensity within the heavy loams on the ridges decreases when the level of the perched water-table of the profile reaches a depth of 100—125 cm and becomes in-significant when the level attains a 175—180 cm depth. The highest capillary supply reaches only 70 cm in the swamp, in peat. Under such conditions, according to Byshov's observations, about 1 mm of water is being accumulated by 1 cm of frozen peat. Thus the quantity of water accumulated in winter by the soils within the swamp-fringed belt and swamp, under the conditions of Central Baraba, was of 40—105 mm, which compared to the annual rainfall of about 300 mm, shows the important role of water supply in winter, to the soil water balance. But the water freezing mechanism itself has not been elucidated, although various experimental tests were undertaken in this field.

Besides liquid water, salts are also being accumulated by the frozen soil. The extent and the form of this accumulation as well as the subsequent salt migration within the soil thawing process have been investigated by Golyakov on the saline soils and on marsh peat solonchaks of the Ubinskoe experimental station (fig. 2).

Simultaneous soil moisture determinations have shown that 88—134 mm of water have been accumulated by frozen soil in the winter of 1948—1949. At the same time, the salt quantity has also increased: at point 7, where the freezing process was slowly progressing at a dep of only 30 cm, a 2.12 times bigger quantity of salts has been accumulated in winter, this process taking place in the lower layer; at point 6, where soil was frozen to a depth of 55 cm, the accumulation was of 1.25 times, being produced in the upper zone, while at point 52, where freezing reached the depth of 60 cm, the accumulation produced also in the upper zone, was of 1.15 times.

It results from the figure that the main place within the salt accumulation process is held by calcium and magnesium sulphates, and to a smaller extent by sodium sulphates followed by sodium, magnesium and calcium chlorides. There are seldom any cases when bicarbonates are present in this process. Thus, an important salt differentiation is being produced by freezing. Its causes are extremely complex and no precise ascertainments were made so far. One can tell that the decrease in sodium carbonates and sulphates solubility at low temperatures is not the single factor of this differentiation.

Salt migration after winter accumulation and during soil thawing process in spring and in summer is of a great interest (see date of July 14). At this date, at point 7, after a swift thawing, the soil has considerably warmed; at point 6, it was the end of thawing process, and at point 52, there were

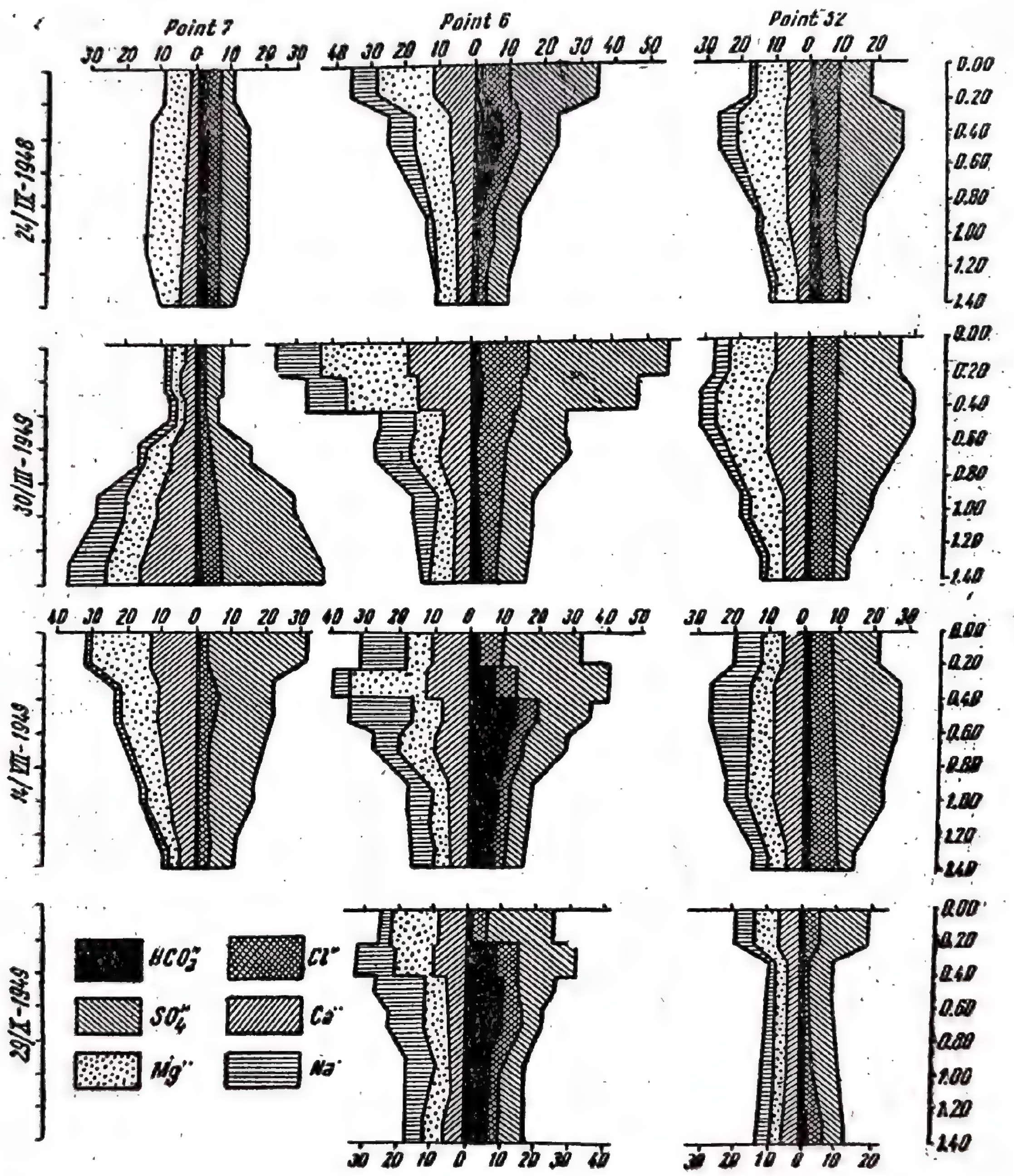

Fig. 2. Changes in the composition of salt solutions on peatboggy saline soils (after Golyakov) m.e. per cubic decimeter of soil.

Point 7: Channel spacing 200 m, snow depth 73—83 cm, slow freezing up to 30 cm, rapid thawing in April; Point 6: Same, snow depth 30 cm, freezing up to 55 cm, slow thawing in July; Point 52: Channel spacing 100 m, snow depth 10—15 cm, freezing up to 80 cm, very slow thawing beginning of August.

still freezing at the depth of 70—80 cm. The observations made showed that early in spring, when soil thawing process starts, an obvious soil desalinization was noticed everywhere. Yet, this desalinization is very little related to the soil washing by the thawing waters, which could not percolate through the frozen soil; it is being explained especially by a thermodiffusion process which takes place as a result of a high temperature gradient up to 20°C in the peat upper (tillable) layer and of 0°C in the frozen soil. The percolation waters, which appear in the soil thawing process above the frozen layer, together with the salts derived from winter accumulation and dissolved into them, are moving downwards. The longer the soil thawing process, the more intensive the desalinization.

Soil desalinization is being produced especially on account of the salts accumulated in winter in very large quantities, namely; first of all, the magnesium, calcium and sodium sulphates are being evacuated, followed by a significant decrease in chloride content, and a simultaneous increase in bicarbonate content. This latter phenomenon must be related to an intensification of the activity of sulphate reducing bacteria in the thawed soil, activity discovered by our previous researches.

As the upper soil layers are getting warmer, evaporation is intensifying, reaching and even surpassing on sunny days: 5 mm/24 h. As a result of this, the vice-versa process occurs, of attracting capillary water and salts to the evaporation surface. The quicker the soil thaws at a great depth (point 7), the more intensively does this process manifest in May-June, with a drought characteristic for these months. The deeper the soil freezes, the more slowly it thaws (point 6 and especially point 52) and more pregnant is manifested the moderating influence of freezing.

The processes studied determine the peculiarities of drainage measures. In the tile and mole drains, the water vapors were condensating during freezing, forming white frost, which in spring was turning into ice plugs, filling the drains with a compact mass. If in spring there is an impermeable frozen soil layer, the drainage action of open channels is being reduced to minimum. In this case the density of the drainage network is determined by the necessity of discharging surface waters, in order that field work should start in due time. Leaching of saline soils can be achieved only in summer, after a certain soil thawing, fact which requires the setting up of reserve water basins, and this cannot be always accomplished in practice. The drainage and reclamation of marshes in the Baraba region, which led to a decrease of soil moisture and a reduction of snow layer thickness, are accompanied by a successive increase of soil freezing depth and of freezing period. As a direct consequence, it has been noticed that after drainage, the marsh was freezing to a depth of 90—100 cm (instead of 40—60 cm), being often frozen through summer. In this case, snow must be retained longer. Thus, the whole drainage system is getting a peculiar characteristic, differing from the system elaborated by a long practice in warmer regions, such as Bielorussia and the Ukraine.

The irrigation system from the Aley basin is near the Rubtzovsk town, on the IInd and IIIrd terraces, of the Aley river. The loamy southern chernozems with alkaline soil (solonetz) spots in the depressions have as subjacent

beds from the depth of 3—5 m a sandy and gravelly alluvium. Although a natural drainage exists, yet owing to exagerated irrigation and leakage from channels, the soils suffer a secondary swamp formation and salinization. The differences between the climate of Baraba forest-steppe and the steppe in the Aley river basin are underlined by the following: an average annual air temperature of 1and +2°C; temperatures sum throughout May-September was 2,223°C and 2,475°C; rainfall over the same months was of 365 and 331 mm; hydrothermic coeficient was of 1.13 and 0.82; days number in a year, with relative air humidity, below 30—45 per cent was of 10 and 91 respectively. Under such conditions, with a stressed continental climate and a snow layer which can be easily blown away, the dry soil is freezing to a depth of 2 m, thawing quickly enough (beginning-middle of May).

According to some observations, approximately 50 mm of water are freezing in winter. The rather rapid soil thawing in spring doesn't contribute to a great extent to desalinization of upper thawed soil layers. In exchange, the rapid raising of temperature and of soil surface evaporation in May, resulted in the rise of the salts accumulated in winter in the tillable layer, which during sowing is being often covered by salt efflorescence. At the same time, a thick crust is being formed and the plantlets become rare; this fact negatively influences particularly the sugar-beet, which in its early growing phase has a reduced salt-tolerance. In order to obtain good sugar-beet crops, with a high sugar content, 2—3 irrigations (500—600 m^3) are necessary. By the usual rains from the end of July till autumn, a certain soil desalinization could be achieved at a depth of 1 m. The winter accumulation of salts opens up a new annual cycle.

We quote here the results of Strugaleva on the salt regime in a 1 m. thick layer of a slightly salinized loamy southern chernozem (fig.3). It has been stated that under the influence of irrigation and torrential rains, the greatest migration mobility was expressed by chlorides, followed immediately by sodium sulphates; the sodium and magnesium bicarbonate content was slightly fluctuating, increasing to a certain extent, concomitently with the decrease of salt general concentration. Another remark was that, towards autumn, the gypsum compounds are increasing and exert a positive influence controlling the alkalinity phenomena.

Experiments and observations were made in 1961 by Oreshkina on the water-salt regime of a sandy-loamy deflated chernozem-like soil in the Iyus valley, at the *Chakasia stationary* of the Forestry and Wood institute within the Siberian of the Soviet Academy of Sciences. An isolated prism was formed, of 150 cm depth, having a cross-sectional area of 140 × 140 cm and saturated with 0.1 n $CaCl_2$. Its upper part was protected against rainfall and evaporation. The ground waters were at a very great depth, having neither the least influence on prism supply (table 3).

This covered monolith received on the whole, during winter, 47.2 mm water; 5.7 mm out of this quantity were contributed by the suspended capillary water labelled with chlor and moved away towards the frozen layer; the rest 41.5 mm being formed of vapors, which by condensation, have greatly diluted the chlorides concentration in the upper layer to a depth of 0.50 m.

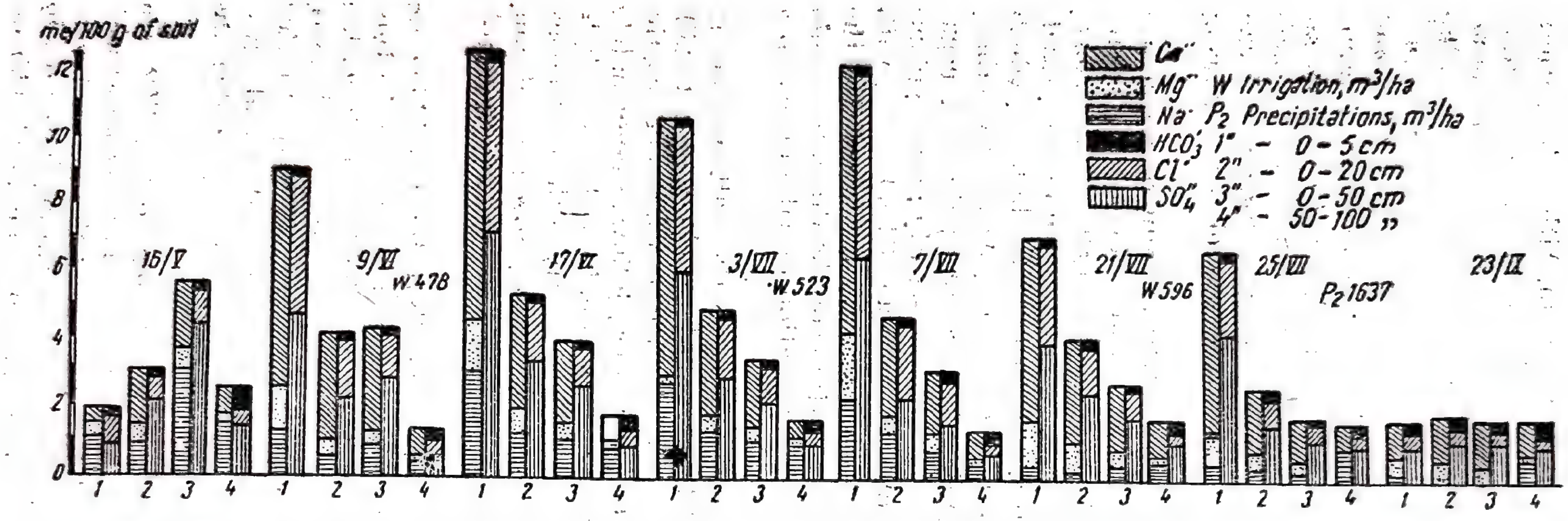

Fig. 3. Salt regime of a secondary salinized southern chernozem at the Aley irrigation system (after Strugaleva).

Table 3

Fluctuations in Reserves of Moisture (mm) and Chlorides (g) in Covered Monolite, according to N. S. Oreshkina

Depth cm	22.IX.1961		26. XII.1961		1.IV.1962		Difference between Sept.-s. April		Moisture addition mm	
	moisture mm	Cl, g	moisture mm	Cl, g	moisture mm	Cl, g	moisture mm	Cl, g	capillary	vapour
0—50	48.8	173	55.4	177	70.5	180	+21.7	+ 7.0	1.0	20.7
50—100	59.1	206	65.7	222	78.3	231	+19.2	+25.0	3.6	15.6
100—150	77.1	246	73.1	249	83.5	253	+ 6.4	+ 7.0	1.0	5.4
0—150	185.1	625	194.2	648	232.3	664	+47.2	+39.0	5.7	41.5

This process of water vapors transport to the frozen layer, took place intensily, particularly over January-February-March, when the process of suspended capillary water displacement to the next layer of 1/2 m depth had already been ended since the end of December.

Thus, in the light moist textured soils with a high-porosity and low field capacity, when the ground waters are at a great depth, the water vapors

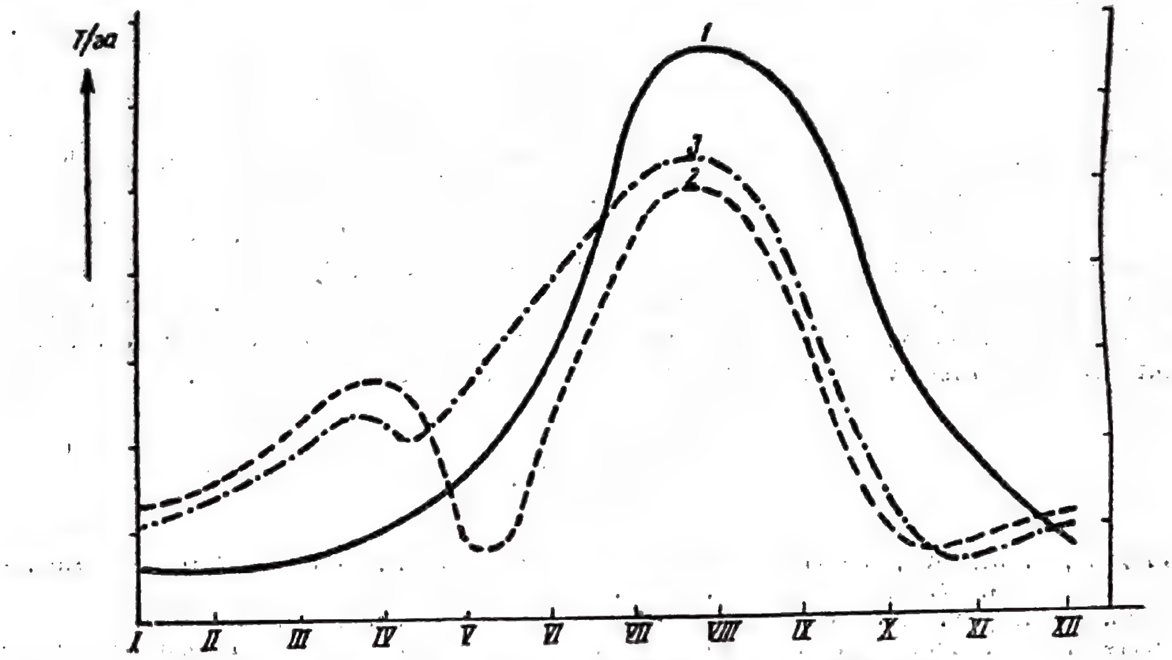

Fig. 4. Annual cycles of salt regimes: *1* — frost-free type; *2* — prolonged frozen type; *3* — intermediate from 1 to 2.

displacement process is active enough, surpassing to a considerable extent the freezing process of capillary film water, so characteristic of clay-loam and clay soils of Baraba region.

In the sandy-loamy desalinized meadow soils, when the ground water table is high (about 230 cm) and the capillary fringe is thick (being equal to 170 cm), under conditions similar to those of the Shyra steppe, an increase in soil water reserve was observed, to a height of 170—210 mm in a two meters layer in winter, being accompanied by an increase in the salt reserves from 3.1—3.6 to 42 kg/m² (especially sodium sulphate) in a 1 m thick layer. In May, these salts were quickly forming effluescence at the soil surface, exerting a negative influence on vegetation, a situation similar to that of the Aley basin steppe.

In conclussion, the following scheme of the salt regime types of hydromorphic and semi-hydromorphic soils from the Western and Middle Siberia (fig.4) was suggested.

The scheme includes three types of soil saline regime. The first type (curve I), with the higheast salinization in summer and the lowest one in winter, has been thoroughly studied for centuries of irrigation practice in Central Asia, Southern Ukraine and other Soviet regions, where the

freezing phenomenon either lacks or is slight. The existence of a single peak in the curve is determined by the whole seasonal variability rate of meteorological, hydrological and other factors.

The second type (curve II), with a high salinization both in winter and summer, and desalinization in spring and autumn, can be found in Siberia and perhaps in all regions with a prolonged freezing-period. Its peculiarities have been analysed, taking as example the Baraba region.

The third type (curve III) represents a passage from the I st to the II nd. It has been studied under the conditions of the irrigation system of the Aley river basin and the Shyra steppe in Chakasia region, where the formation of this type is due to soil freezing at a great depth and to a very short but hot summer. A particularly negative influence on young plants is being played here by the increase of salts in May.

It is quite obvious — and this has been underlined above — that the various reclamation and management actions form their cultivated (cropping) variants of the water and salt soil regime, variants which are not analysed in the above scheme, but which represent for the purpose in view, an important task for the present research work and for practical experiment.

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SUMMARY

By stationary investigations of hydromorfic soils of Siberia a considerable increase of capillary water and watersoluble salt amounts in winter has been ascertained, which was caused by the deep and prolonged freezing. In contrast to soils of more warm areas of the USSR, where the intensive decrease in soil salinity during winter is going on, in soils of Western and Middle Siberia the increase of salinity during the winter season is observed with subsequent water-freshing of the upper layer during the spring season and with a second peak of salinization in summer. The third type of the regime salinization, which is the transitional one, is typical for soils with deep freezing but with relatively rapid thawing in spring.

RÉSUMÉ

On a constaté par des investigations stationnaires, sur les sols hydromorphyques de Sibérie, une ascension considérable de l'eau capillaire et des quantités de sels solubles dans l'eau, pendant l'hiver, provoquée par le gel profond et prolongé. En contraste avec les sols de certaines régions plus tempérées de l'URSS, où la diminution intensive dela salinité pendant l'hiver continue, dans les sols de la Sibérie occidentale et centrale l'augmentation de la salinité pendant la saison d'hiver est observée comme étant suivie par une désalinisation de la couche supérieure pendant la saison de printemps, avec un second sommet de salinisation pendant l'été. Le troisième type de régime de salinisation, qui est de transition, est typique pour les sols à gel profond et degel relativement rapide au printemps.

ZUSAMMENFASSUNG

Bei Standortuntersuchungen über hydromorphe Böden in Sibirien wurde die beträchtliche Zunahme des Kapillarwassers und der wasserlöslichen Salzmengen im Winter nachgewiesen, die durch das tiefe und anhaltende Einfrieren verursacht wurde. Im Gegensatz zu den in temperierteren Gegenden der UdSSR gelegenen Böden, wo die starke Abnahme der Bodensalzhaltigkeit während des Winters fortdauert, wird bei den Böden West- und Mittelsibiriens die Zunahme des Salzgehaltes im Winter nebst einer darauffolgenden Wasserversüssung in der Oberschicht im Frühling und einer zweiten Versalzungsspitze im Sommer beobachtet. Der dritte Typus von Versalzungshaushalt, der einen Übergangstypus darstellt, ist für Böden mit tiefgehendem Einfrieren aber verhältnismässig frühem Auftauen im Frühling kennzeichnend.

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UNTERSUCHUNGEN ÜBER DEN WASSERHAUSHALT ÖSTERREICHISCHER BÖDEN

H. FRANZ [1]

Der starke Wechsel im geologischen Aufbau, im Relief und in den Klimaverhältnissen, der für die österreichischen Landschaften charakteristisch ist, bedingt es, dass hier auf kleinem Raum Böden mit sehr verschiedenem Wasserhaushalt auftreten. Mit Rücksicht auf die grosse wirtschaftliche Bedeutung des Bodenwassers haben wir vor einiger Zeit damit begonnen, den Wasserhaushalt einiger österreichischer Böden vergleichend zu studieren. An den bisherigen Untersuchungen waren die Herren Nestroy (1961), Bronner (1963), Müller (1964) und Ghobadian (1964) beteiligt.

An erster Stelle wurde der Waserhaushalt von Lössböden studiert. Hierfür war einerseits der bodenwirtschaftliche Gesichtspunkt massgebend, dass Lössböden in Österreich weit verbreitet sind und zu den fruchtbarsten Böden des Landes gehören und anderseits der Umstand, dass die Wasserbewegung im Löss sehr langsam vor sich geht und daher relativ leicht verfolgbar ist. Später wurden auch sehr bindige, sowie recht leichte, ja sogar Salzböden in die Untersuchungen einbezogen. Während der Vegetationszeit tritt in Schönwetterperioden auf allen nicht grundwasserbeeinflussten Böden Österreichs ein beträchtlicher Rückgang des Wassergehaltes auf.

In den niederschlagsreicheren westlichen Teilen des nördlichen Alpenvorlandes werden bei 750—900 mm Jahresniederschlag die sommerlichen Verluste bei Braunerden und Parabraunerden aus Löss gewöhnlich schon durch die Herbstniederschläge voll wieder ausgeglichen, während dies im östlichen Teile Niederösterreichs bei 550 bis 650 mm Niederschlag und einer ausgeprägten sommerlichen Trockenperiode meist nicht der Fall ist. Die Tschernoseme dieses Raumes erreichen die Wassersättigung bis zur Feldkapazität oft erst im Laufe des Winters und beginnen meist schon bald nach der Schneeschmelze wieder auszutrocknen.

Über die gesamte nutzbare Regenspeicherung österreichischer Lössböden geben die folgenden von Bronner (1963) an einer Parabraunerde des Linzer Raumes ermittelten Werte Aufschluss:

Wassergehalt in der durchwurzelten Bodenschicht (0—100 cm) ausgedrückt in mm Niederschlag

bei 0,3 Atmosphären Saugspannung 345,1 mm
bei 15 Atmosphären Saugspannung 172,9 mm.

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Die Differenz beider Werte ergibt 172,2 mm, die annähernd der nutzbaren Regenspeicherung im Sinne Sekeras, bzw. der nutzbaren Kapazität im Sinne Baumanns entsprechen. Setzt man diesen Wert gleich 100 Prozent, so ergeben sich aus dem aktuellen Wassergehalt zu verschiedenen Terminen des Jahres 1960 und 1961 unter drei verschiedenen Kulturpflanzen die in Tabelle 1 angeführten Gehalte an pflanzennutzbarem Wasser in Prozenten der nutzbaren Kapazität:

Tabelle 1

Gehalt an pflanzennutzbarem Wasser in % der nutzbaren Kapazität unter verschiedenen Kulturpflanzen

Datum	Kulturpflanzen		
	Winterroggen	Rotklee	Zuckerrübe
17.X.59	—	24	70
5.III.60	116	120	114
11.IV.60	87	83	97
9.V.60	68	55	88
1.VI.60	58	42	91
23.VI.60	49	33	71
22.VII.60	115	86	110
23.VIII.60	93	92	95
8.X.60	111	111	97
11.VI.61	—	86	95
7.VII.61	—	49	56
7.VIII.61	—	42	27
14.VIII.61	—	57	50
27.IX.61	89	42	32
7.X.61	78	25	16
13.XI.61	111	71	68

Nimmt man mit Ceratzki und Korte (1961) an, dass 30 bis 50% der nutzbaren Kapazität pflanzenverfügbares Wasser im Boden vorhanden sein müssen, um optimale Ernten zu ermöglichen, so sieht man, dass diese Wasserversorgung selbst unter so günstigen Bedingungen, wie sie auf tiefgründigen Lössböden bei Linz (mit 9,1°C Jahresmitteltemperatur und 844 Jahresniederschlagsmenge im 50 jährigen Durchschnitt sowie Maximum der Niederschläge im Sommer) vorliegen, zeitweilig unter das Optimum absinkt.

Im niederschlagsärmeren Osten Österreichs ist die Wasserversorgung der Kulturpflanzen schon auf Lössböden viel schlechter. Auf ungünstigeren Substraten tritt hier ohne künstliche Beregnung häufig extremer Wassermangel auf.

Schon die Parabraunerden des Linzer Raumes weisen nach Bronner, (1963) wenn sie nicht künstlich bewässert werden, im Sommer eine Abnahme des Wassergehaltes bis zu 100 cm Tiefe auf. Bei Tschernosemen aus Löss im nordöstlichen Niederösterreich hat Nestroy (1961) im Laufe des Jahres Schwankungen des Wassergehaltes bis zu 180 cm Tiefe nachweisen können. Dies beweist, dass die Pflanzen hier bis zu so bedeutender Tiefe Wasser aus dem Boden entnehmen.

Die gesamte nutzbare Wasserspeicherung ist je nach Profilaufbau, Struktur und Textur des Bodens sehr verschieden, wie die Tabelle 2 erkennen lässt.

Tabelle 2

Nutzbare Wasserspeicherung bei einigen Bodenprofilen

Boden	durchwurzelter Raum (cm)	nutzbare Wasserspeicherung (mm Neiderschlag)
Parabraunerde aus Löss b. Linz	0—100	172,2
Pseudogley aus Flyschmergel b. Wien	0— 80	74,6
Tschernosem aus sandigen Seesedimenten bei Apelton am Neusiedlersee	0— 80	87,9

Tabelle 3

Wassergehalt des Bodens in einer mit Alexandrinerklee angebauten Versuchsparzelle

Datum	Ges. Wassergehalt in mm	pflanzennutzbares Wasser in mm in:				
		0—80 cm	0—20 cm	20—40 cm	40—60 cm	60—80 cm
31.7.62	241,0	21,9	—	4,4	4,6	12,2
10.8.62	212,8	0,6	—	—	—	0,6
18.9.62	218,8	3,4	—	—	—	3,4
21.11.62	329,6	107,8	38,2	26,0	22,6	21,0
18.12.62	353,4	131,6	43,8	32,4	30,6	24,8
14.3.63	352,2	103,4	33,2	25,4	12,8	12,0
8.5.63	329,8	108,0	36,6	28,2	21,2	22,0
5.6.63	284,4	62,6	21,2	16,8	13,0	15,8
12.7.63	225,4	7,6	—	0,2	0,6	6,8
23.7.63	183,8	—	—	—	—	—
26.7.63	171,0	—	—	—	—	—
30.8.63	228,8	29,6	29,6	—	—	—
28.11.63	286,8	65,0	28,4	20,8	9,6	6,2

Die Untersuchung eines Pseudogleys aus Flyschmergel am westlichen Stadtrand von Wien durch Müller (1964) ergab eine gesamte Wasserspeicherung bei Feldkapazität in 0—80 cm Tiefe von 296 mm Niederschlag. Hievon sind 221,8 mm so fest gebunden, dass sie nicht pflanzenaufnehmbar sind, woraus sich die geringe nutzbare Wasserspeicherung von 74,6 mm ergibt. Diese wird von den Pflanzen in Trockenzeiten, wie die Messungen Müllers (1964) zeigen, rasch verbraucht. Die Messungen wurden auf einer Versuchsparzelle durchgeführt, die im Jahre 1962 ungenutzt blieb. Im Jahre 1963 wurde am 16. Mai Alexandrinerklee mit etwas Grasbeimengung angesät, der Klee war am 5. Juni aufgelaufen, am 16. Juni etwa 15 cm hoch, am 9. Juli erfolgte der erste Schnitt. Die letzte Mahd erfolgte am 13. September, am 24. November 1963 wurde der Bestand umgebrochen. Aus den in kurzen Abständen wiederholten Messungen des aktuellen Wassergehaltes sind in Tabelle 3 einige charakteristische Ergebnisse wiedergegeben.

Zu den Zahlen ist zu bemerken, dass in den oberen Horizonten sowohl im Sommer 1962 als auch in den Sommermonaten 1963 der Wassergehalt während mehrerer Wochen unter die dem permanenten Welkepunkt entsprechenden Werte absank, was offenbar eine Folge der Evaporation war. Da gleichzeitig der Boden von einem zwar sehr dürftigen, aber doch noch lebenden Kleebestand bedeckt war, muss die Pflanzendecke in dieser Zeit aus dem äusserst dichten Substrat unter 80 cm Tiefe Wasser bezogen haben.

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ZUSAMMENFASSUNG

Die unterschiedlichen geologischen, morphologischen und klimatischen Verhältnisse bedingen, dass in Österreich Böden mit sehr verschiedenem Wasserspeicherungsvermögen vorkommen. Die nutzbare Speicherung beträgt bei einer Parabraunerde der Umgebung von Linz a. Donau im durchwurzelten Bodenprofil (oberste 100 cm des Bodens) annähernd 172,2 mm, in einem Pseudogley aus Flyschmergel des Wiener Raumes dagegen in den oberen 80 cm, unter denen das nicht mehr durchwurzelte Gestein folgt, nur 74,6 mm. Der aktuelle Wassergehalt der Böden schwankt im Laufe des Jahres in Abhängigkeit von Witterungsverlauf und Pflanzendecke stark. Auch im gemässigt humiden Klima von Linz tritt auf besten Lössböden zeitweilig eine Unterversorgung der Pflanzen mit Wasser auf. In einem Tschernosem des pannonischen Klimagebietes im Osten von Niederösterreich wurden Schwankungen des Wassergehaltes bis zu 180 cm Tiefe festgestellt. Der Wasservorrat wird dort oft erst zu Ende des Winters bis zur Feldkapazität aufgefüllt.

SUMMARY

Owing to different geological, morphological and climate conditions, the Austrian territory presents soils with a great diversity of water storage capacity. The available water storage of a parabrown soil of the Linz region amounts approx. to 177.2 mm in the root-zone of the profile (upper 100 cm of soil), whereas in a pseudogley on a flysh marl of the Vienna region, it amounts only to 74.6 mm in the upper 80 cm, below this the existant rocks being without any root vegetation. The present water content of the soils varies significantly in dependence of climate and plant cover conditions all the year round. Even in the moderately humid climate of Linz, temporary deficiency in water supply to plants occurs on the best loess soils. On a chernotzem of the pannonian climatic region of East-Austria, variations in water content up to a depth of 180 cm were recorded. The water storage often reaches its field capacity only at the end of winter.

RÉSUMÉ

Les conditions géologiques, morphologiques et climatiques différentes déterminent l'existence en Autriche de sols très différents en ce qui concerne leur capacité d'emmagasinage pour l'eau. Pour un sol parabrun dans des environs de Linz sur le Danube, l'eau emmagasinée utilisable dans la zone radiculaire du profil (les 100 cm supérieurs du sol) se situe à environ 172,2 mm ; au contraire, dans un pseudogley provenant d'une marne de flysch de la région de Vienne, elle ne monte, dans les 80 cm supérieurs sous lesquels se trouve la roche qui ne présente plus d'enracinement, qu'à 74,6 mm. L'humidité actuelle des sols varie fortement au cours de l'année, en fonction des conditions atmosphériques de la couche végétale. Même dans le climat modérément humide de Linz se manifeste temporairement, sur les meilleurs sols de loess, une alimentation déficitaire des plantes avec de l'eau. Dans un chernozem de la zone climatique pannonique à l'Est de l'Autriche Inférieure, on a constaté des variations de l'humidité jusqu'à une profondeur de 180 cm. La réserve en eau jusqu'au niveau de la capacité au champ, n'y est souvent atteinte qu'à la fin de l'hiver.

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EFFECT OF MOISTURE ON PROCESSES OF LANDSLIDES IN BROWN SOIL ON MARL CLAY

H. RESULOVICH[1]

Soil moisture, its amount, conditions and nature of percolation, is a very important soil factor, which determines its development and fertility. In spite of its importance, little work has been carried out on the water dynamics and particularly on its effect on soil creep.

The studies reported here examined the distribution and changes of moisture content in a brown soil and the effect of water on soil creep.

Brown soils are to be found in the surroundings of Sarajevo. In a paper published earlier (Resulovich, 1957) we discussed some questions concerning soil genesis on this parent material-marl clay, which has some special characteristics. Recent soil dynamics which characterizes the latest phase in the development of this soil after deforestation shows that the soil in this area has turned unstable as a consequence of wrong management, and that on very large surfaces processes have begun to develop which disrupt it (figures 1 and 2). On the surfaces of this area, where normal pedogenesis is possible, i.e. where processes of landslide and erosion have no major effect, brown soil shows the following characteristics: depth of $A+(B)$ horizons goes to 30—40 cm. the humus content A-horizon of is no more than 4.50 per cent and that of (B)-horizon is 2.50 per cent. In both horizons effervescence to HCl is not positive; $CaCO_3$ content of the C-horizon is as great as 21 per cent. Soil texture in the two upper horizons is silty clay loam and in the C-horizon is as great as 21 per cent. Soil texture in the two upper horizons is silty clay loam, and in the C-horizon is clay (content of under 0.002 mm particles — 54.27 per cent pH in n KCl in the A-horizon is 5.61, in the (B)-horizon 5.80 and in the C-horizon 6.95.

In some places (on slopes) of this area the processes of soil creep are very intensive, bringing the land into such conditions that it cannot be used at present for agricultural purposes. Cropping in such places is possible only on flat surfaces or on gentle slopes. The area with steep slopes is only used today as meadows (or is occupied by old disused orchards).

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Fig. 1. Landslide processes cause an abnormal position of fruit trees.

Fig. 2. Landslide processes on marl clay in the surroundings of Sarajevo (Audica Brdo-Slatina).

Tabele 1

Maximum and minimum values of moisture content, field capacity and wilting point of the brown soil

Horizons	Depth cm	Maximum moisture content	Minimum moisture content	Difference	Field capacity	Wilting percentage
		per cent on weight basis				
A_p	0—1	41.1	3.6	37.5	33.3	10.7
	1—2	40.5	3.7	36.8		
	2—5	37.6	8.7	28.9		
	5—11	37.2	15.4	21.8		
	11—20	39.0	16.4	22.6		
(B)	20—30	36.9	14.6	22.3	30.2	12.2
	30—40	36.3	13.8	22.5		
C	40—50	30.7	16.4	14.3		
	50—60	30.8	16.8	14.6	27.8	16.0
	67—00	31.8	17.2			

On the basis of the results of the present investigation on moisture dynamics, we sought to determine the relationship between soil moisture and landslide, and, also, the period during the year when the process of landslide is the most intensive.

In connection with the nature of soil creep it was necessary to examine moisture dynamics in the soil profile at different depths, so as to explain the causes of the processes.

In order to solve this question we measured the moisture content during 1962 and 1963 (from April 1962 to April 1963) in the soil profile up to a depth of 70 cm. Soil samples were taken twice a month (every 10th and 25th of the month). In the upper horizons the samples were taken at smaller depth-intervals, as follows: 0—1, 2, 2—5, 5—11 and 11—20 cm; in the deeper horizons the depth intervals were larger: 10 cm. From the surface horizons soil samples were taken with a small spade, and from the other depths with Pürckhauer's auger. There were four replications of each sampling depth, and in the analysis we give the mean values.

Besides moisture content, we also determined the hygroscopic coeficient of the samples. On separate samples we examined field capacity (by Vukcanovich's (1956) method) and wilting percentage (with oaths) by the method described by Rode (1960).

The data on moisture dynamics are plotted as chronoisopletes (figure 3). In figure 3 we can see great changes in the moisture content during the year at various depths of the soil profile. Especially large moisture fluctuations were found in the 0—2 cm layer. Here the differences between maximum and minimum values were 37.5 and 36.8 per cent (on weight basis). For the other depths the changes during the research period were smaller, e.g.14.6 per cent for the depth of 60—70 (table 1).

The data show the very dynamic nature of the moisture regime in the surface horizons, where the highest losses of moisture occur. Especially clearly these differences can be seen from chronoisopletes, i.e. from their density.

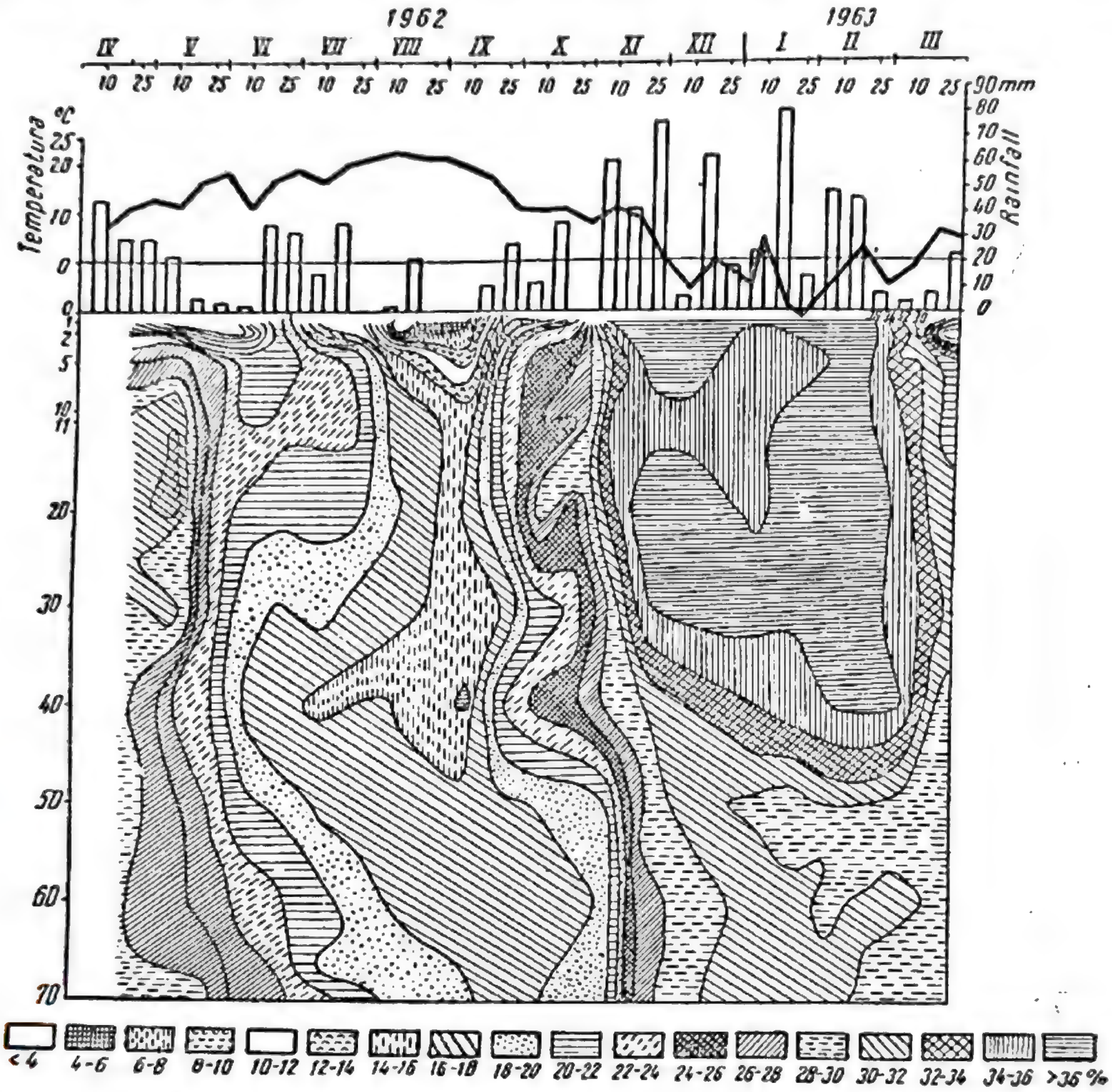

Fig. 3. Chronoisopletes of moisture content (on weight basis).

Surface horizons are exposed to the greatest changes, especially during the period from April to October. Some other research workers also pointed out such large fluctuations of moisture in the surface horizons (Hide, 1954; Parkhomenko, 1957; Rodionovski, 1959).

The data of the analyses also show that the most intense drying was in the surface layers, where moisture content was as low as 3.6 and 3.7 per cent (10th August). These figures approach the hygroscopic coefficient. During such extreme drying the soil surface was covered with wheat stubble, so that the extreme drying was probably a result of evaporation only. Such an intense dessiccation affected only the surface layer up to 2 cm. But at depth deeper

than 2 cm moisture content was up to five times higher (3.7 per cent in comparison with 12.5 per cent). At the depths of 5—70 cm moisture content was in no case below the wilting point. The loss of moisture in the deeper horizons must be primarily attributed to the influence of slow drainage and to the effect of transpiration before the end of July i.e. of harvest and evaporation.

This drying of the upper layers up to 2 cm actually brings about a considerable reduction of evaporation. Penman (1963) reported that this dried layer in a bare soil serves as some kind of mulch (self-mulching). Russell (1952) states that after such a strong drying of the upper layer of 2 cm the process of evaporation falls to 1/10. This "static layer", according to Hide (1954), becomes the main impediment for a further movement of moisture from deeper layers, thus causing a considerable reduction of its loss. This process of moisture loss by evaporation depends as well on weather as on soil conditions. Parkhomenko (1957) states that the highest evaporation from the soil occurs when soil moisture is near field capacity, but it does not go beyond it.

This drying during the summer period results in the formation of cracks which go down the profile. The formation of these cracks must be attributed to a high capacity for swelling and shrinking of the soil as a result of its high clay content, and probably to the peculiar properties of its clay minerals. However, it is interesting to emphasize that the formation of such cracks during the dry season is also one of the reasons which causes an increasing instability of the soil and its creep when it is water-saturated in the wet season.

On the other hand, the wetting of the soil profile is highest from the second half of November to March when moisture content was higher than field capacity, indicating an intense saturation during this period. The maximum mosture content was 41,9 per cent at the depth of 0—1 cm in November. At this time, i.e. 10th November, the layers below 40 cm were considerably drier, with moisture content above the wilting percentage: 18.1—19.6 per cent. At the end of October the rainfall increased the moisture content in the upper horizons, especially at depths up to 20 cm.

The moisture content in the deeper horizons increases later, in December, as a result of water drainage from the upper horizons. In the period from November to March higher precipitations and lower temperature caused the wetting of the whole profile. This high saturation of the soil, especially in the upper horizons, shows that during this interval the most considerable landslides can be expected. Actually, after saturation of the upper horizons and because of the weak permeability of the clay substratum, a slide plane appears under the sodden upper soil horizons. With increasing water content the cohesion force decreases, and the soddenness of the soil mass can be considered as the main cause of the creep. Our investigations show that these processes of landslide ought to be most active in the second half of November and from the second half of February to the beginning of March. In the period between December and the beginning of February low temperature and frozen soil prevent landslide.

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SUMMARY

Investigation on water dynamics in a brown soil developed on marl clay showed that the most intense fluctuations in moisture content were in the thin surface layer of 0—2 cm. In this layer the dessiccation processes lowered moisture content in August up to the hygroscopic coefficient.

During the dry season deep and wide cracks formed and they greatly contributed to the instability of the land and to its movement in the wet season.

The maximum soil content was recorded in the November-February period.

The investigations show that in this area (on slopes) and in these conditions, land slide processes were particularly strong in November, in the second half of February and at the beginning of March. In this period, the whole profile was saturated with water, the soil was very unstable and the flow of the sodden soil mass reached its maximum, causing high disruptions of land.

RÉSUMÉ

Des recherches sur la dynamique de l'eau dans un sol brun développé sur argile marneuse ont montré que la fluctuation la plus intense de l'humidité se produisait dans la couche de surface de 0—2 cm. Dans cette couche le processus de desséchement a diminué en août l'humidité, jusqu'au coefficient hygroscopique.

Pendant la saison sèche de profondes et larges fissures se sont formées et elles ont contribué largement à l'instabilité des terres et à leur déplacement pendant la saison humide.

Le sol a présenté l'humidité maximum pendant la période novembre février.

Les recherches montrent que, dans ces conditions, les processus de glissement de terrain dans cette aire (sur les pentes) étaient particulièrement forts en novembre, dans la seconde moitié de février et au début de mars. Pendant cette période, le profil tout entier était saturé d'eau, le sol était très instable et l'écoulement de la masse de sol mouillée a atteint le point culminant, ce qui a causé de grandes dislocations de terre.

ZUSAMMENFASSUNG

Untersuchungen über die Wasserdynamik in der auf Mergelton entwickelten Braunerde zeigten, dass die intensivsten Schwankungen im Wassergehalt in der dünnen Oberflächenschicht von 0—2 cm waren. Der Austrocknungsprozess sank in dieser Schicht, im Monat August, bis zur Hygroskopizitätszahl.

Während der Trockensaison bildeten sich tiefe und breite Spalten, welche beträchtlich zur Unbeständigkeit des Bodens und zu seiner Verschiebung während der nassen Saison beitrugen.

Der grösste Gehalt an Wasser fand sich im Boden während der November-Februar Periode.

Diese Untersuchungen zeigten, dass die Erdrutschprozesse in diesen Flächen (auf Abhängen) unter diesen Umständen besonders stark im November, in der zweiten Hälfte Februar und zu Märzbeginn waren. Das ganze Profil war in dieser Periode mit Wasser gesättigt, der Boden war sehr unstabil und das Fliessen der vernässten Bodenmasse erreichte siene Höhe, was grosses Bodenbreissen verursachte.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

DIE BÖDEN IM GEBIET DES „HANSÁG" UND IHRE BODENPHYSIKALISCHEN EIGENSCHAFTEN

V. LESZTÁK, K. DARAB [1]

Es ist seit langer Zeit bekannt und sowohl durch Untersuchungen als auch in der Praxis bestätigt, dass die physikalischen und Wasserhaushaltseigenschaften der Böden bei der Entwässerung und bei der Bewässerung eine entscheidende Rolle spielen. Diese Eigenschaften haben besondere Bedeutung bei den kulturtechnischen und landwirtschaftlichen Massnahmen in solchen Gebieten, in denen sich die Böden unter der Wirkung von Oberflächen- und Untergrundwasser ausgebildet haben und noch heute unter deren Einfluss stehen. Ein solches Gebiet ist in Ungarn in der Kleinen Ungarischen Tiefebene das Gebiet des „Hanság". Hier entwickelten sich die Böden unter übernässten Verhältnissen und die hier vorhandenen Torfböden, Moorböden, Wiesen-Moorböden und Wiesenböden stehen auch noch heute unter unmittelbarem Einfluss des Untergrundwassers. Der Untergrund dieser Böden ist hauptsächlich tonig und sehr kalkreich, und es besteht ein grosser Unterschied in den Wasserhaushaltseigenschaften zwischen den tiefer gelegenen kalkreichen, mineralischen, tonigeren Schichten und den oberen Schichten, welch letztere an organischen Substanzen sehr reich sind (Tab. 1).

Die physikalischen und Wasserhaushaltseigenschaften der Moorböden und der Wiesen-Moorböden sind grundsätzlich im Zusammenhang mit den physikalischen, chemischen und hydrologischen Eigenschaften der Torfe und der organischen pflanzlichen Substanzen, aus welchen diese Böden gebildet sind, zu betrachten. Diese Eigenschaften sind folgende:

1) hohe Wasserkapazität,

2) eigenartige Porosität,

3) grosse Veränderung der physikalischen und Wasserhaushalteigenschaften.

Das Raumgewicht dieser Böden ist in den obersten Schichten recht klein, was mit den grossen Mengen der organischen Substanzen im Zusammenhang steht. Die Werte der Volumengewichte in diesen Schichten sind 0,6 — 0,9. Die Werte der Raumgewichte in tiefen Schichten (1,26, 1,35, 1,41) charakterisieren bereits verdichtete Schichten (Tab. 2).

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Tabelle 1

Die chemische Beschaffenheit der Böden

Profil	Tiefe der Probennahme	$CaCO_3$ %	Humus %
Fertöd 1	2—9	7,21	42,24
	15—24	21,48	27,90
	31—40	29,50	25,98
	44—53	42,80	
	64—73	25,19	
Fertöd 2	4—13	9,73	23,55
	25—35	29,96	20,24
	45—55	29,79	30,07
	70—80	26,18	
	90—100	42,46	
	120—130	18,55	
Kistölgyfás 3	1—15	im Spuren	20,76
	28—37	„	28,90
	50—60	„	16,67
	74—84	Ø	31,25
	110—120	Ø	39,80
Mosonszentjános 4	5—15	42,05	
	24—34	48,68	29,21
	43—53	44,38	27,23
	60—70	40,23	24,77
	85—95	12,59	
	115—125	16,78	
	150—160	16,78	
	190—200	16,93	
Mosonszentjános 5	5—15	15,19	
	23—33	64,83	40,25
	38—48	75,54	33,80
	54—64	54,56	
	80—100	13,43	
	120—130	20,98	

Tabelle 2

Die physikalische Beschaffenheit der Böden

Profil	Tiefe der Probenahme	Spez. Gewicht	Raum-Gewicht	Gesamt Porosität
1	Oberfläche	2,57	0,95	63
	5	2,57	1,18	54
	20	2,62	1,14	56
	52	2,70	1,35	50
2	Oberfläche	2,48	0,75	69
	5	2,46	0,77	68
	23	2,58	0,99	61
	50	2,69	1,26	53
3	Oberfläche	2,33	0,61	73
	5	2,20	0,57	74
	26	2,58	0,93	63
	60	2,71	1,09	59
4	Oberfläche	2,44	0,77	68
	5	2,44	0,85	65
	25	2,64	1,12	57
	53	2,75	1,41	48

Das spezifische Gewicht dieser Böden hängt auch von der Menge der organischen Substanzen ab. In den Schichten, welche an organischen Verbindungen reich sind, ist der Wert des spezifisches Gewichtes kleiner als 2,5. In den tieferen Schichten vergrössert sich im Zusammenhang mit zunehmender Verdichtung dieser Wert auf 2,63—2,75 (Tab. 3).

Die Gesamtporosität der Böden haben wir mit Hilfe des spezifischen Gewichtes und des Raumgewichtes berechnet. Die Gesamtporosität ist in den obersten Schichten sehr gross und von der Art der Bearbeitung des Bodens und von dem Pflanzenbestand abhängig. In den dichteren, unter der gepflügten Oberfläche liegenden Schichten vermindert sich der Wert der Gesamtporosität rasch (Tab. 2).

Diese Böden haben eine gut entwickelte poröse, körnige Struktur. Bei der Ausbildung der Struktur spielten wahrscheinlich die Eisen- und Kalkverbindungen der Böden im Hanság eine Rolle. Die Porosität in den obersten gepflügten Schichten setzt sich aus den groben Poren zwischen den Bodenteilchen und den feinen Poren in den Bodenkrümeln zusammen. Diese Zusammensetzung der Porosität sichert gute Wasserhaushaltseigenschaften in den gepflügten Schichten. In den unter der gepflügten Oberfläche liegenden Schichten verändert sich die Zusammensetzung der Poren und die Porosität vermindert sich deutlich. Wenn die Oberfläche dieser Böden unbedeckt ist, bilden sich nach unseren Beobachtungen bei starker Austrocknung dieser Schichten Schrumpfrisse mit Weiten von 0,5—1 cm. Das Wasser dringt alsdann nur durch diese Schrumpfrisse in den Boden ein. Die Oberfläche jener Böden, die mit Pflanzen gleichmässig bedeckt sind, schrumpft nicht.

Die Wasserdurchlässigkeit war in allen Profilen gut (Abb.1). Die grösste Wasserdurchlässigkeit hatte der torfige Moorboden. Wir können uns merken, dass sich die Infiltration schon in erster Stunde vergrössert hatte, und diese Erhöhung während der ganzen Zeit der Beobachtung angedauert hat. Das können wir damit erklären, dass in diesem Profil keine verdichtete Bodenschicht existiert. Die Wasserdurchlässigkeit der verschiedenen Schichten können wir auf Abbildung 2 sehen. Infolge des hochliegenden Untergrundwassers und der grossen Wasserdurchlässigkeit erreichte das Bewässerungswasser den Spiegel des Untergrundwassers. Das können wir an dem Infiltrationsprofil des Bodens

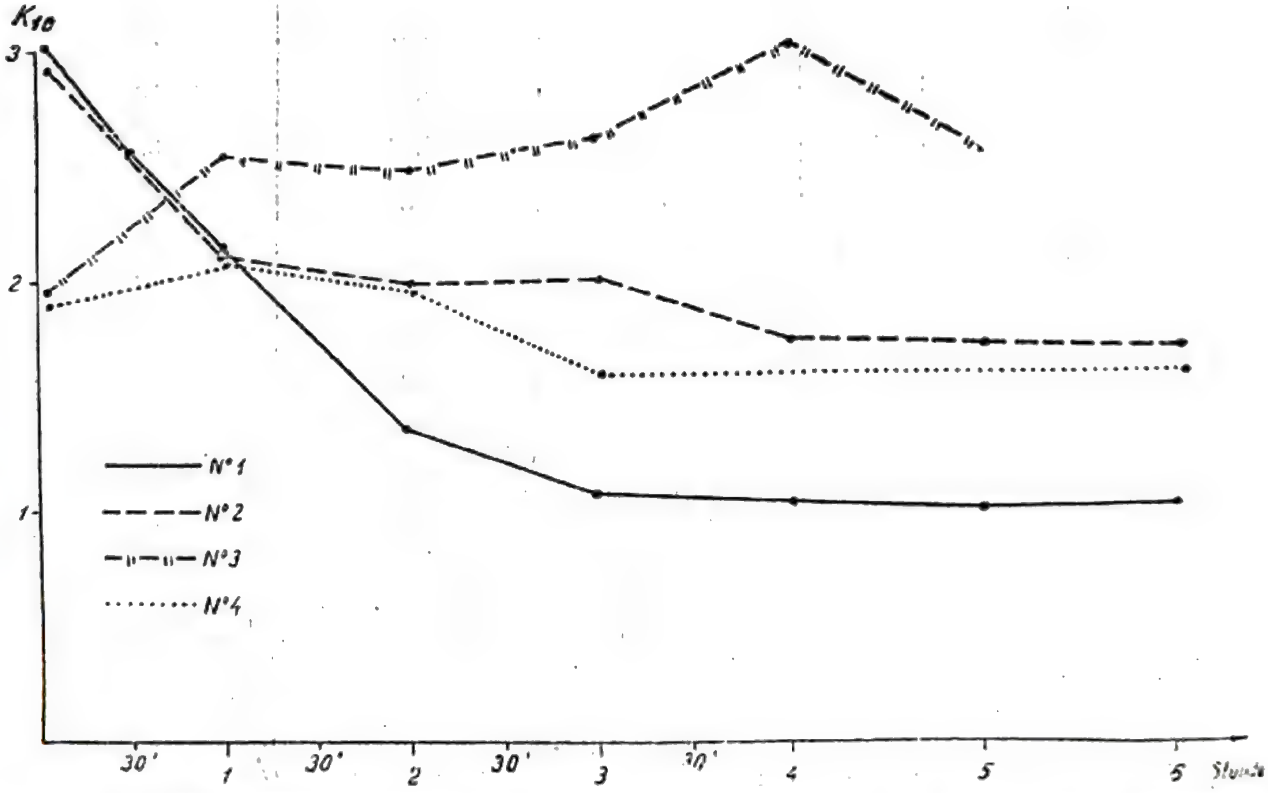

Abb. 1. Das Wasserleitvermögen der Böden (mm/min)messend an der Oberfläche der Böden.

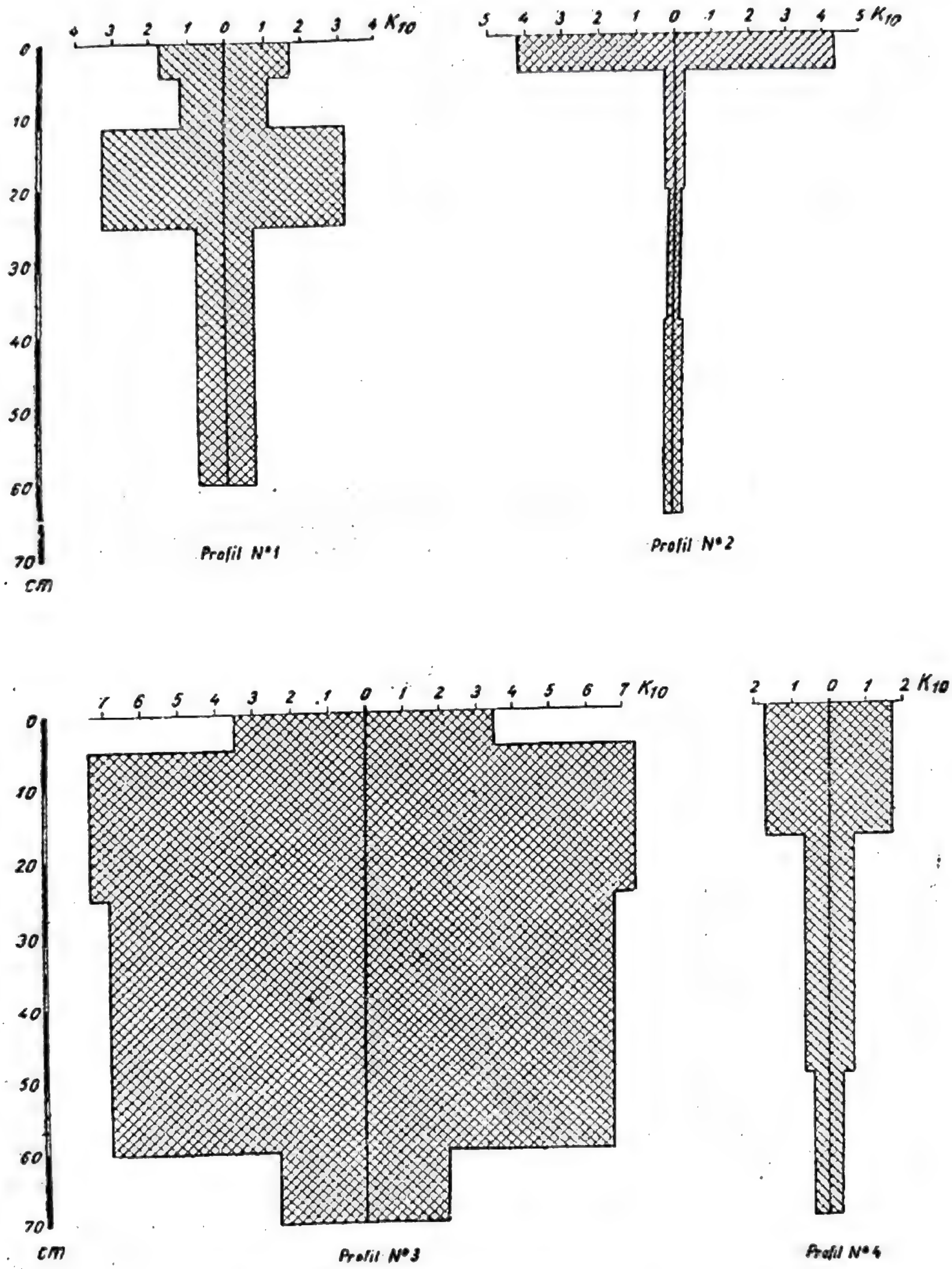

Abb. 2. Das Wasserleitvermögen der Böden (mm/min).

sehen (Abb.3). In diesem Fall erfolgte nach seitwärts kein Wasserabfluss. Ein ganz anderes Bild zeigt der landwirtschaftlich bearbeitete torfige Moorboden. Hier konnten wir auch eine hohe Wasserdurchlässigkeit messen, aber der Charakter dieser Durchlässigkeit war ganz anders. In diesem Fall hatten die oberen Bodenschichten zwar eine grosse Wasserdurchlässigkeit, doch die

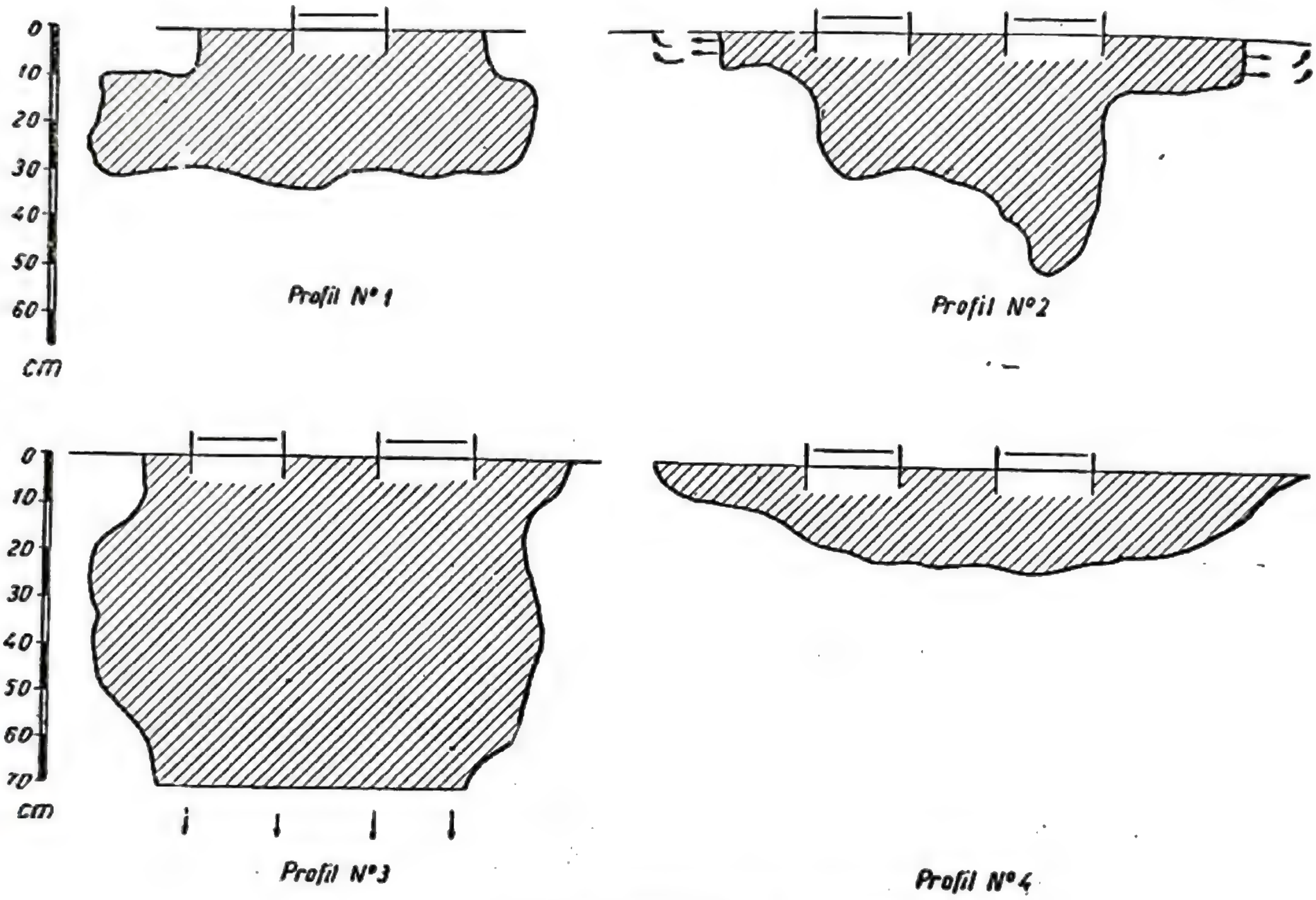

Abb. 3. Infiltrationsprofile der Böden.

unterliegenden Schichten waren sehr verdichtet und hatten nur eine niedrige Wasserleitfähigkeit. Das Bewässerungswasser lief seitwärts ab, und schon nach zwei Stunden erschienen an der Oberfläche des Bodens nasse Flächen in zwei Meter Entfernung von dem Rahmen, und nach vier Stunden war die Oberfläche des Bodens in einer Weite von 5—6 m von dem Rahmen durchfeuchtet. Das zeigen gut die Infiltrationsprofile (Abb.3). Dichte, wasserdurchlässige Schichten wurden auch bei den Profilen Nr.1 und Nr. 4 beobachtet. Die halbzerfallenen Pflanzenreste und die grosse Menge der organischen Kolloide, welch letztere sich im Gelzustand befinden, bestimmen die Wasserhaushaltseigenschaften dieser Böden. Darauf deuten die hohen Werte der minimalen Wasserkapazität — welche höher sind als bei Mineralböden und der hohe Welkekoeffizient (Tab. 3).

Infolge des hohen Wasserhaltungsvermögens der Böden hat die gepflügte Oberfläche einen weiten Bereich an pflanzenverfügbarem Wasser (Abb.4).

Tabelle 3

Feuchtigkeitsgehalt bei der Probenentnahme und die Feldkapazität der Böden

Profil	Tiefe der Probenahme	Hygroskopizität	Feuchtigkeit	Feldkapazität	
				I	II
1	0—5	3,08	16,27	34,25	—
	5—10	2,92	15,17	25,33	—
	10—20	2,44	13,10	23,97	—
	20—30	—	13,14	20,01	—
	30—40	—	16,30	17,08	—
	40—50	0,61	13,60	16,93	—
	50—60	—	14,66	15,69	—
	60—70	—	15,36	14,80	—
	70—80	—	21,70	21,02	—
	80—90	—	21,84	—	—
	90—100	—	21,82	—	—
	100—120	—	21,82	—	—
	120—140	—	20,57	—	—
	140—160		20,93	—	
2	0—5	5,30	7,14	48,90	46,80
	5—10	5,88	31,74	47,26	46,31
	10—20	—	41,12	45,54	43,43
	20—30	6,69	—	34,48	34,74
	30—40	—	27,15	27,87	31,28
	40—50	1,43	25,68	25,81	32,67
	50—60	—	25,78	25,97	25,05
	60—70	—	23,34	25,89	23,17
	70—80	—	24,34	25,05	27,40
	80—90	—	25,52	27,80	25,74
	90—100	—	23,52	29,12	26,83
3	0—5	7,87	26,38	72,56	78,99
	5—10	10,63	46,01	66,85	70,48
	10—20	—	34,40	60,60	45,89
	20—30	4,88	27,95	37,23	33,38
	30—40	—	29,43	32,74	35,47
	40—50	—	29,34	29,80	30,60
	50—60	1,04	27,81	27,75	30,31
	60—70	—	27,66	28,99	33,03
	70—80	—	27,77	27,73	32,32
	80—90	—	23,93	26,16	27,76
	90—100	—	27,15	24,77	27,86
	100—110	—	26,96	—	25,98
4	0—5	6,24	16,68	50,25	45,03
	5—10	6,61	24,97	43,05	41,98
	10—20	—	25,10	36,92	42,34
	20—30	4,64	16,68	20,81	19,09
	30—40	—	—	16,94	17,74
	40—50	—	—	15,92	16,43
	50—60	0,89	—	16,52	15,29
	60—70	—	—	16,07	10,21
	70—80	—	—	14,13	17,49
	80—90	—	—	14,04	13,33
	90—100	—	—	12,30	10,04
	100—120	—	—	13,09	—
	120—140	—	—	8,02	—

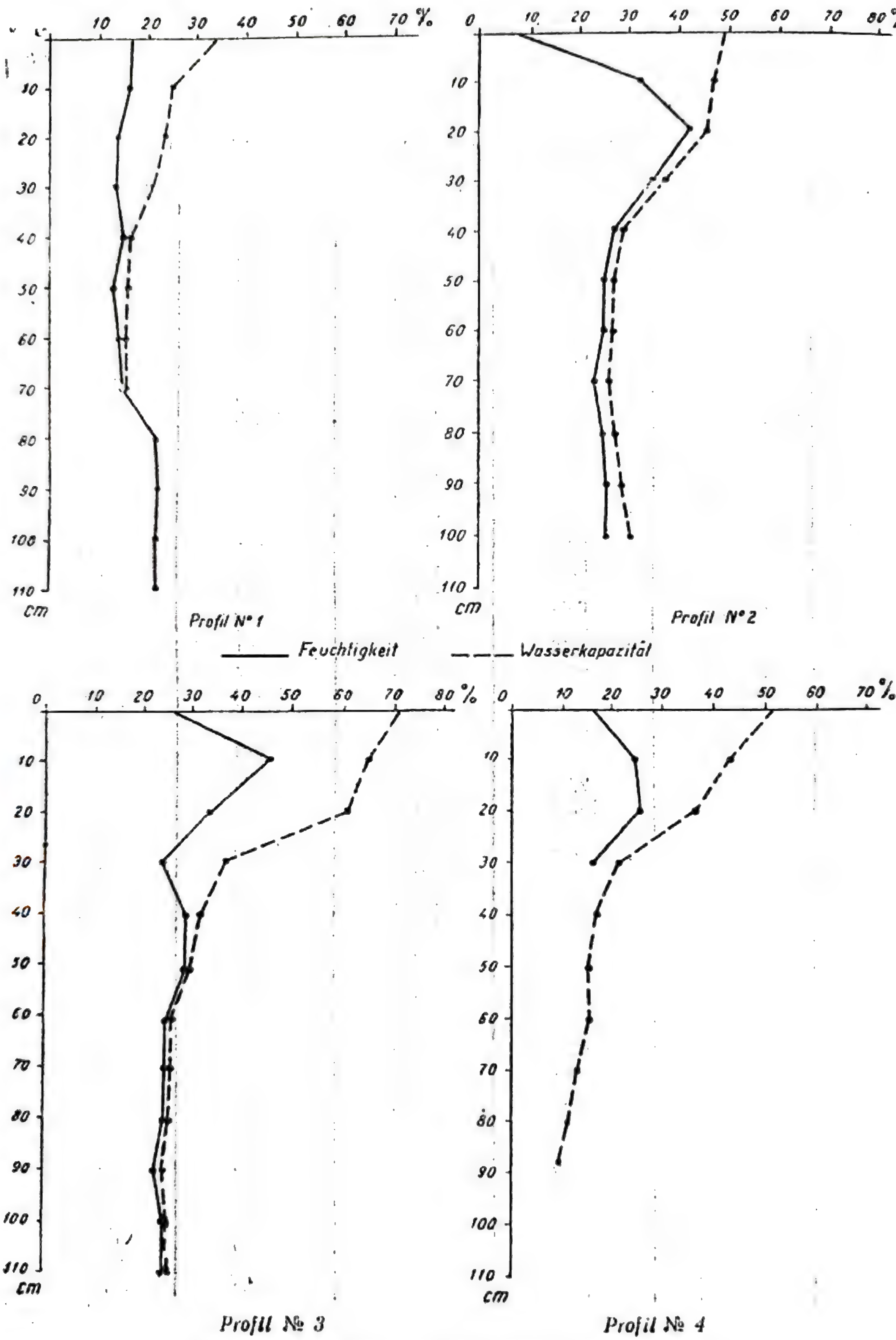

Abb. 4. Feuchtigkeit und Feldkapazität der Böden im %.

Der Wasserhaushalt dieser Moor- und Wiesenmoorböden ist charakterisiert durch einen scharfen Unterschied in den Feuchtigkeitsverhältnissen der gepflügten Oberflächenschichten und der darunterliegenden Schichten. Die Ursachen der grossen Feuchtigkeitsunterschiede in verschiedenen Bodenschichten sind erstens die verschiedenen Wasserhaushaltseigenschaften der einzelnen Bodenschichten und zweitens die Zerstörung der natürlichen Verbindung zwischen den Bodenschichten infolge der Bodenbearbeitung, besonders des Pflügens. Infolge der hohen Wasserkapazität des Bodens dringt das Regen- und Bewässerungswasser ein und erhöht die Feuchtigkeit des gepflügten Oberbodens bis zum vollen Wert der minimalen Wasserkapazität. Das in den Boden eindringende Wasser bleibt aber — wie unsere Untersuchungen zeigen — nach der Sättigung des Bodens bis zur minimalen Wasserkapazität in den obersten Bodenschichten, obgleich die darunter gelegenen Schichten ungesättigt waren.

Diese Erscheinung können wir mit der Verschiedenheit der Porosität und der Verdichtung der verschiedenen Schichten erklären. Von der Eigenart des Wasserhaushaltes rührt es her, dass das Regen- und Bewässerungswasser — nach unseren Ergebnissen — nur selten tiefer als 30 cm in den Boden eindringt (Abb.3). Die geringe Tiefe der Durchfeuchtung führt zur schnellen Austrocknung der oberen Schichten und infolgedessen zu Wassermangel für die Pflanzen.

Nach den Ergebnissen unserer Untersuchungen haben wir in diesen Böden im Gebiet des „Hanság" zu einer Untergrundbewässerung geraten

ZUSAMMENFASSUNG

Die physikalischen Eigenschaften der Torf-, Moor- und torfig-sumpfigen Wiesenböden sind in Zusammenhang mit den Eigenschaften der Torfe und der organischen pflanzlichen Substanzen, aus welchen diese Böden gebildet sind, zu betrachten. Die Böden im Hanság-Gebiet sind durch ihre hohe Wasserkapazität und eigenartige Porosität gekennzeichnet. Scharfe Unterschiede in der Porosität, Wasserdurchlässigkeit, minimalen Wasserkapazität, im Feuchtigkeitsgehalt und in der Skala der aktiven Feuchtigkeit der Ackerkrume und des Unterbodens sind gleichfalls kennzeichnend. Diese Erscheinungen sind teils im Vorhandensein eines kompakten, kalkreichen, mineralischen Horizontes zu suchen, teils aber den Einwirkungen des Ackers und der Pflege der landwirtschaftlichen Kulturen zuzuschreiben. Das Bewässerungs- und Niederschlagswasser dringt nur selten tiefer als bis 30 cm in den Boden ein, und die Nutzungstiefe der Profile wird durch die Tiefe des kompakten Horizontes stark beeinflusst. Auf Grund der vorgenommenen Untersuchungen wurden auf diesem Gebiet bei den gegebenen Bodentypen Untergrundbewässerung durch die Regulierung des Grundwasserspiegels vorgeschlagen.

SUMMARY

The physical properties of peaty, boggy and meadow-soils are to be considered as related to the properties of the peats and of the organic substances composing these soils. The soils of the Hansag region are characterized by a high water capacity and a peculiar porosity. Sharp differences in porosity, water permeability, field capacity, moisture content and available moisture range of soil and subsoil are also characteristic. This is partly due to the presence of a compact, calcareous mineral horizon and partly to tillage and cropping effects. Irrigation and rainfall water seldom penetrate deeper than 30 cm, the available profile depth being significantly influenced by the depth of the compact horzion. On the basis of these investigations, subsoil irrigation by regulation of the ground water table was recommended for these soils.

RÉSUMÉ

Les propriétés des sols tourbeux, marécageux et des sols de prairie tourbeux-marécageux sont liées aux propriétés des tourbes et des substances organiques des plantes, dont ces sols sont formés. Les sols de la région de Hanság sont caractérisés par leur haute capacité en eau et par une porosité spéciale. Des différences très prononcées entre le sol et le sous-sol quant à la perméabilité à l'eau, la capacité au champ, l'humidité et l'intervalle de l'humidité accessible leur sont également caractéristiques. Les phénomènes son dûs en partie à la présence d'un horizon minéral calcaire compact et, d'autre part, aux effets des travaux du sol et les soins données aux cultures. L'eau d'irrigation et celle des précipitations ne pénètre que rarement dans le sol à une profondeur dépassant 30 cm et la profondeur utilisable des profils est fortement influencée par la profondeur de l'horizon compact.

Basé sur ces recherches, on a proposé pour les types de sol de cette région, l'irrigation souterraine tout en réglant le plan d'eau de la nappe phréatique.

DISKUSSION

L.D. BAVER (U.S.A.). Was the lack of movement of water into the lower layer o Profile no. 2 due to a plow sole or to natural impervious horizons?

K. DARAB. Natural impervious horizons.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

SUR L'ESTIMATION QUANTITATIVE DE L'HUMIDITÉ DU SOL DES STATIONS FORESTIÈRES PAR LES ÉLÉMENTS DU CLIMAT

ROMAN I. FLOROFF[1]

Sur l'humidité du sol il y a très peu d'observations. Cela est valable tant pour le nombre des places que pour la durée des périodes de mesurage. Voilà pourquoi aujourd'hui les différents travaux dans le domaine de la typologie forestière se limitent, pour la caractéristique quantitative de l'humidité du sol, aux appréciations : sec, frais, humide etc.

C'est logique de considérer qu'on peut obtenir une plus précise appréciation de l'humidité du sol par des observations directes. Les données de telles observations, cependent, d'après Turc (1958), ont une importance locale et selon ces données il est difficile de déterminer les valeurs moyennes de l'humidité du sol et de les comparer avec les données météorologiques. À cela il faut ajouter que pour l'éclaircissement de cette question sur un vaste territoire avec un relief varié, tel qu'est la territoire couvert de forêts dans tous les pays, et cela pour une période de plusieurs années, un vaste réseau de places d'observations avec les appareils et le personnel respectif et, pour le moins, une période de 10—15 années d'observations sont nécessaires.

En dernier lieu ce problème est résolu sur la base des éléments du climat, pour lesquels il y a plus d'observations et cela pour des dizaines d'années. À cet égard il faut indiquer les méthodes de Turc (1958), de Kortüm (1958), de Penmann (cité par Boudyko, 1959), de Boudyko (1959) et de Boudyko et Zoubenok (1961). Parmi ces méthodes, la plus convenable pour les conditions d'un climat plus sec et pour des terrains inclinés est la méthode de Boudyko.

Cette méthode est élaborée sur la base de la solution commune de l'équation du bilan thermique de la surface active, et du bilan d'eau du sol.

La méthode de Boudyko consiste dans les suivantes :

L'humidité du sol à la fin de la période qui nous intéresse est égale à l'humidité du commencement de la période, à laquelle on ajoute les précipitations et de laquelle on soustrait l'évapotranspiration et l'écoulement de surface, ou

$$W_2 = W_1 + N - É - f, \qquad (1)$$

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où W_2 est l'humidité du sol à la fin de la période, W_1 — l'humidité du sol au commencement de la période, N — les précipitations, $\acute{E}$ — l'évapotranspiration et f — l'écoulement de surface.

Pour déterminer le cours annuel des réserves d'eau dans le sol on prend comme valeur initiale de l'humidité du sol (au début de l'année) la capacité au champ du sol. Dans le cas des terrains boisés ou préparés pour reboisement l'écoulement de surface a des valeurs très petites qui pour une période moyenne de plusieurs années tend vers zéro. L'élément principal et le plus dificile à estimer de l'équation du bilan d'eau du sol (1) reste l'évapotranspiration. Cet élément d'après Boudyko est égal à l'évapotranspiration potentielle tant que l'humidité est supérieure à l'humidité de rupture des liens capillaires:

$$E = E_0 \text{ quand } W > W_{cr}, \tag{2}$$

où E — l'évapotranspiration, E_0 — l'évapotranspiration potentielle, W — l'humidité actuelle du sol et W_{cr} — l'humidité de rupture des liens capillaires (l'humidité critique). Si l'humidité du sol est plus petite que celle de larupture des liens capillaires, alors l'évapotranspiration est proportionnelle auxreserves productives d'eau et on obtient la relation suivante:

$$E = E_0 \frac{W}{W_{cr}}. \tag{3}$$

À son tour on détermine l'évapotranspiration E_0 sur la base du bilan de radiation de la surface humide du sol et du flux thermique dans le sol:

$$E_0 = \frac{R_0 - B}{L},$$

où $\acute{E}_0$ est l'évapotranspiration potentielle, R_0 — le bilan de radiation de la surface active humide, B — le flux thermique dans le sol et L — la chaleur latente d'évaporation de l'eau.

La méthode de Boudyko a été vérifiée en U.R.S.S. par l'auteur, par Berliand (1952) et par Zoubenok et Diatchenko (1956). Nous avons aussi vérifié, en Bulgarie, cette méthode, sur un relief très varié. La première vérification a été faite en 1956 près de Sandanski dans des terrasses de reboisement. Le 18 mai la réserve d'eau initiale a été de 187 mm. Le 12 juin les réserves d'eau selon la méthode directe ont été évaluées à 115 mm et d'après Boudyko à 112 mm; le 8 juillet à 43 et 40 mm et le 18 juillet à 46 et 57 mm. La vérification suivante a été faite dans les forêts de Youndola en 15 places d'observation. Les résultats sont montrés dans le tableau 1.

Des différences plus grandes résultant en quelques cas d'une forte teneur en squelette et, des difficultés pour déterminer la capacitè d'eau des sols qui en résulte. Malgré cela, en général les résultats sont satisfaisants. Ces résultats montrent qu'on peut apliquer la méthode de Boudyko aussi pour des terrains inclinés couverts ou non de forêts. Cela est possible pour une période moyenne de plusieurs années ainsi que pour une année séparée, si on tient comte des caractéristiques physiques du sol.

Tableau 1

L'humidité du sol (en% de poids) déterminée par la méthode directe et par la méthode de M. I. Boudyko

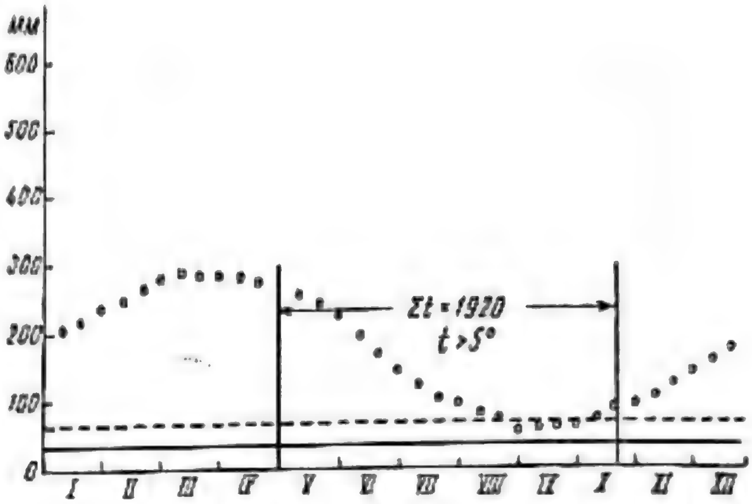
No. des places d'observation	L'humidité du sol		
	par la méthode directe	par la méthode de Boudyko	Différences
1 (1)	7,4	5,7	1,7
2 (5)	11,4	10,4	1,0
3 (19)	8,9	10,1	1,2
4 (6)	11,1	10,4	0,7
5 (13)	13,3	13,6	0,3
6 (3)	19,2	19,3	0,1
7 (34)	6,1	4,0	2,1
8 (33)	9,0	7,5	1,5
9 (35)	6,8	5,4	1,4
10 (10)	12,8	13,5	0,7
11 (39)	9,0	10,3	1,3
12 (20)	10,1	7,2	2,9
13 (22)	15,2	17,0	1,8
14 (37)	10,0	10,4	0,4
15 (36)	9,3	6,7	2,6

Nous avons utilisé la méthode de Boudyko pour déterminer le cours annuel des réserves d'eau pour une période de plusieurs années dans les places mentionnées dans le tableau 1, en Youndola dans les Rhodopes, en liaison avec les classes de production des forêts. Les hautes classes de production correspondent à de hautes réserves d'eau pendant la période de végétation, les basses classes de production à de petites réserves d'eau. Dans les figures 1, 2 et 3 on voit le cours annuel des réserves d'eau en mm par mois. On voit aussi la somme des températures de la période de végétation au-dessus de 5° C et la durée de la période de végétation (les lignes parallèles à l'ordonnée). Parallèlement à l'abscisse on voit le point de flétrissement — la ligne interrompue — et l'hygroscopicité maximale — ligne noninterrompue.

Au cours annuel des réserves d'eau de la figure 1 correspond une forêt de troisième clases de production à *Pinus silvestris* 8 et *Picea excelsa* 2 ; dans la figure 2 la forêt est formée par *Abies alba* 8 et *Picea excelsa* 2, de la deuxième classe de production et dans la figure 3 — par *Abies alba* 10, de la première classe de production.

Nous avons utilisé aussi la méthode de Boudyko pour déterminer le cours annuel des reserves d'eau des sols pour une période moyenne de plusieurs années pour une épaisseur de 50 et 100 cm sur des terrains inclinées de la Bulgarie. On a déterminé les dates moyennes de l'épuisement des réserves productives d'eau, la durée moyenne de la période á l'humidité oscillant autour du point de flétrissement, les dates moyennes quand l'humidité du sol approche l'hygroscopicité maximale et la fréquence des années aux réserves inférieures à l'eau „morte". Les calculs ont été faits pour trois variétés texturales de sols : sable limoneux, limon argileux et limon argileux fin. Les différences en ce qui concerne la date de l'épuisement des réserves productives d'eau (pendant l'été) dépendent, à une agrotechnique similaire, de l'épaisseur du sol. À une épaisseur de 50 cm les réserves productives d'eau s'épuisent 15—20

Fig. 1. Cours annuel des réserves d'eau dans le sol et la somme des températures au dessus de 5°C dans les stations caractéristiques pour *Pinus silvestris* L. IIIe classe de production.



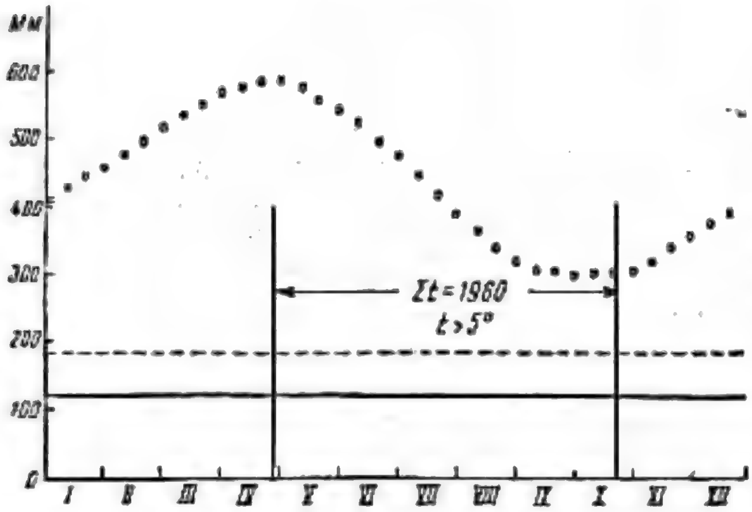


Fig. 2. Cours annuel des réserves d'eau dans le sol et la somme des temperatures au dessus de 5°C dans les stations de *Abies alba* Mill. et *Picea excelsa* Link, IIe classe de production.

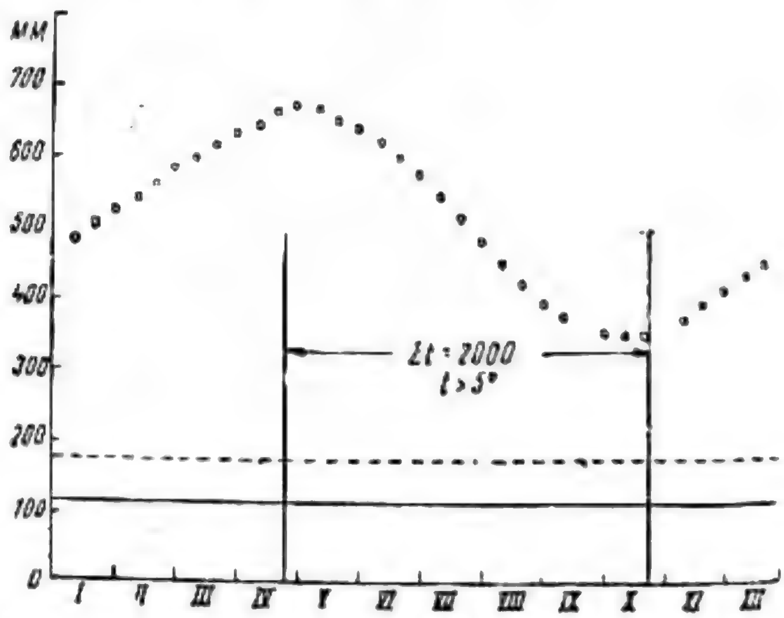


Fig. 3. Cours annuel des réserves d'eau dans le sol et la somme des températures au dessus de 5°C dans les stations caractéristiques pour *Abies alba* Mill, Ie classe de production.

jours plus tôt dans un sable limoneux que dans un limon argileux fin. La différence entre le limon argileux et le limon argileux fin est de 2—3 jours.

Pour une période moyenne de plusieurs années le cours annuel des réserves d'eau a été déterminé pour des sols avec l'hygroscopicité maximale de 4%, le point de flétrissement 6% et la capacité de rétention 22%, chiffres obtenus selon les courbes de Rode (1955). Pour ces sols on évalue l'humidité de la rupture des liens capillaires à 75% de la capacité au champ. Nous avons aussi élaboré une carte des groupes de districts climatiques avec des dates rapprochées de l'épuisement des réserves productives d'eau et de l'apparition des réserves d'eau inaccessibles. Dans la légende de la carte sont montrées les dates moyennes respectives pour différentes expositions et pentes. La carte ne renferme que les épaisseurs de 50 et 100 cm. La carte explique nombre d'aspects en liaison avec le reboisement de ces terrains. Elle peut être utile aussi pour d'autres buts en dehors de la sphère des intérêts de l'économie forestière. Elle donne une trés belles image du cours annuel des réserves d'eau du sol dans les différentes régions du pays, sur les différentes expositions et pentes ainsi que pour d'autres épaisseurs, excepté celles de 50 et 100 cm.

Les résultats obtenus sont dûs à l'application de la méthode de Boudyko, qui peut être considerée comme universelle, en tant que se basant sur la solution commune de l'équation du bilan thermique de la surface active et sur le bilan d'eau du sol. C'est pourquoi, bien que cette méthode soit une méthode climatologique, elle peut être utilisée, avec certaines modifications. aussi pour des buts écologiques.

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RÉSUMÉ

L'auteur a vérifié la méthode de Boudyko pour la détermination du cours annue des réserves d'eau du sol par les élements du climat sur des terrains inclinés en Bulgarie. I a constaté une différence entre les résultats suivant cette méthode et la méthode gravimétrique de 0,1 jusqu'à 1,8% du poids du sol absolument sec (en trois cas les différences ont été de 2,1 jusqu'à 2,9%, à cause de la teneur en squelette).

La vérification a permis de déterminer le cours annuel des réserves d'eau dans le sol pour une longue période en Bulgarie, sur des terrains forestiers avec différentes expositions et pentes, et une épaisseur de 50 et 100 cm.

D'autre part l'auteur a déterminé le cours annuel des réserves d'eau dans le sol en quelques points des montagnes Rhodope en liaison avec la distribution des espèces forestières et la classe de production.

Selon l'auteur, la méthode de Boudyko peut être utilisée pour des buts écologiques, après avoir pris en considération les propriétés hydro-physiques des sols.

SUMMARY

The author has checked Boudyko's method for the quantitative estimation of soil moisture storage on climatic basis in Bulgaria on sloping lands. Differences between soil moistures determined by Boudyko's method and the gravimetric method were 0,1—1,7% (by weight of the absolute dry soil) (in three instances the difference was 2,1—2,9% on account of the skeleton content).

The check has permitted to determine the yearly trend of soil moisture storages for a long period in Bulgaria on forest land with various exposures and declivities, and for a depth of 50 and 100 cm.

On the other hand the author has determined the yearly trend of soil moisture storages in several points of the Rhodopes-Mountains in relationship with the distribution of the forest species and the production classes of the forests.

In the author's opinion, Boudyko's method can be used for ecologic purposes, after considering the soil moisture relationship.

ZUSAMMENFASSUNG

Der Autor hat die Methode Boudykos für die Bestimmung der Bodenwasserreserven durch die Klimaelemente in Bulgarien bei Hanggeländen nachgeprüft. Er hat einen Unterschied zwischen den Ergebnissen nach dieser Methode und jenen nach der gravimetrischen Methode von 0,1 bis 1,8% von dem Gewicht des absolut trockenen Bodens festgestellt (nur in drei Fällen war der Unterschied 1,2—2,9% wegen des grossen Gehalts an Skelett).

Die Nachprüfung hat dem Verfasser ermöglicht, den Jahreslauf der Bodenwasserreserven für eine lange Periode in Bulgarien bei Forstgeländen mit verschiedenen Neigungen und Expositionen und von einer Mächtigkeit von 50 und 100 cm zu bestimmen.

Andererseits hat der Verfasser den Jahresgang der Bodenwasserreserven in einigen Punkten im Rhodopengebirge in Verbindung mit der Holzartenverbreitung und den Produktionsklassen der Bestände festgestellt.

Nach dem Verfasser kann die Methode Boudykos für ökologische Zwecke verwendet werden. Es müssen aber die hydro-physikalischen Charakteristiken des Bodens in Betracht gezogen werden.

DISCUSSION

J. W. HOLMES (Australia). It is true that the measurement of soil changes under forests gives very variable results, depending upon the location of sampling, rainfall interception by the forest canopy and other factors. However, the use of calculated evaporation by such methods as Mr. Floroff describes (Boudyko, Penman, Turc etc.) may also be misleading, unless checked. We have good experimental evidence that the evaporation from pine forests during the rainy season in southern Australia exceeds by 2½ times the evaporation from pasture land. The Penman calculation of evaporation for this region, using the meteorological data of a standard weather station, agrees within 15% with the measured evaporation from the pasture land.

R. FLOROFF. Mr. Holmes a précisé qu'on doit être très attentif quand on emploie des méthodes étrangères en ce domaine, parce qu'en Australie on a constaté de très grandes différences entre l'évaporation actuelle et l'évapotranspiration potentielle : la première était 2 fois et demie plus grande. C'est une observation très importante. En Bulgarie aussi on a constaté

de telles différences : l'évapotranspiration actuelle était 1,2—1,4 fois plus grande que l'évapotranspiration potentielle (D. Dilkov. *L'influence de la lucerne sur le régime d'eau dans les chernozems de nord de la Bulgarie*,vol. I des résumés des communications du Congrès).

L'explication de ces différences est très simple. L'évapotranspiration potentielle en ces cas a été calculée par des formules empiriques, lesquelles d'un côté comprennent des coefficients empiriques, et de l'autre, sont déduites et valables pour une période moyenne de plusieurs années, tandis que l'évapotranspiration actuelle a été déterminée seulement pour la période de végétation d'une année concrète.

Seulement dans des cas exceptionnels on peut obtenir des valeurs égales.

La méthode de M. I. Boudyko, que nous utilisons, ne comprend pas des coefficients empiriques. C'est une méthode qui est basée sur la loi de la conservation de l'énergie, laquelle est une loi universelle.

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I. 16

L'HUMECTATION TOTALE DES SOLS DE LA RÉPUBLIQUE POPULAIRE ROUMAINE

IOSIF UJVÁRI[1]

La notion d'humectation totale du sol, comme un composé du bilan hydrologique, a été introduite dans la littérature par Lvovitch en 1950. Elle est notée par W_0 et représente la somme de l'évapo-transpiration (Z_0) et de la quantité d'eau qui par l'infiltration (I_0), ou par la condensation (C_0) enrichit la nappe phréatique. Les réserves qui alimentent la nappe phréatique reviennent à leur tour dans le réseau hydrographique et représentent l'alimentation souterraine de celui-ci (U_0). En ce qui concerne le profil pour plusieurs années, on peut proposer l'équation suivante:

$$I_0 + C_0 = Z_0 + U_0 = W_0,$$

$$W_0 = X_0 - Y_s.$$

Autrement dit, l'humectation totale des sols est la quantité d'eau qui reste temporairement dans le sol après les précipitations (X_0) et qui, après les ecoulements superficiels (Y_s), se consomme par l'évapo-transpiration et par l'alimentation de la nappe phréatique.

Il en résulte que, parmi les composants du bilan hydrologique seul W_0 représente la quantité d'eau disponible pour la végétation, Y_s s'écoulant des versants sans aucun effet biogène. La rétention de Y_s pour l'augmentation de W_0 a, dans les régions arides, une importance capitale (Lvovitch, 1963). Dans ce but, on applique avec succès des méthodes agro-sylviques pour la rétention de l'eau.

La détermination de la valeur W_0 s'effectue par deux méthodes: par l'utilisation des données de l'observation hydrologique pour les bassins hydrographiques et par la méthode des parcelles expérimentales. Ces deux méthodes permettent ensemble de grandes synthèses térritoriales et aussi des études de détail — quand on étudie l'un des effets des facteurs physico-géographiques sur le plan local.

Dans notre pays on a entrepris des études dans les deux directions. Les premières études dans lesquelles ont été discutés quelques-uns des problèmes de l'humectation totale du sol de notre pays ont paru en 1957.

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Cette année-là Lăzărescu et Panait (1957) se fondant sur des données d'observations hydro-météorologiques assez limitées, ont fait une première esquisse pour W en Roumanie,

Cet ouvrage a été révisé par les auteurs (*Monografia geografică a R.P.R.*, 1960). Cependant, en 1959, a paru une carte dressée par Ujvári (1959) dans laquelle on fait une série de précisions. L'accumulation de beaucoup de données ces dernières années a permis de détailler d'une manière plus minutieuse la carte W_0 — ce qui représente l'objet du présent ouvrage.

Ultérieurement, les grands avantages pour l'agriculture de la connaissance des valeurs de W_0 et aussi de ses variations en fonction des méthodes agrotechniques appliquées devenant encore plus évidents, en est passé dans notre pays á la organisation de stations expérimentales permettant d'étudier le bilan hydrologique. Aux stations expérimentales de l'.I.C.A., où l'on étudie le problème de l'érosion, on peut saisir les changements provoqués pas les diverses méthodes agrotechniques sur l'écoulement superficiel. En 1961, la Chaire de Géographie physique de l'Université „Babeş-Bolyai" et des collaborateurs de l'Institut Agronomique „Dr. P. Groza" de Cluj ont organisé une serie d'observations spéciales en ce sens et en 1954 a été menée à bout l'installation de la station de Voineşti, appartenant au Comité d'État des Eaux (C.S.A.), où l'on entreprend aussi des observations. Les résultats sont en cours de publication (Ujvári et al. 1962).

LES TRAITS GÉNÉRAUX DE LA REPARTITION TERRITORIALE DE L'HUMECTATION TOTALE DES SOLS ET DE L'INDICE K_w EN ROUMANIE

Le présent ouvrage a utilisé les données d'observation de 339 postes hydrométriques, avec les valeurs Z_0 et U_0 qui y ont été déterminées. Pour dresser la carte de l'indice d'humectation totale des sols $K_w = \dfrac{W_0 \text{ mm}}{X_0 \text{ mm}}$ on a utilisé aussi la carte des précipitations moyennes pluriannuelles, publiée par Stoenescu dans la *Monografia geografică a R.P.R.* (1960). Les valeurs moyennes dans les deux cas ont été déterminées pour des périodes de plus de 30, respectivement 60 ans, correspondant aux nécessités de la détermination des normes statistiques.

Par l'analyse des données fournies par les observations, on a établi une interdépendence étroite entre le milieu physico-géographique et l'humectation totale des sols. On en a dégagé toute une série de lois naturelles générales d'interdépendance et interaction avec les sols de notre pays, des contrastes différents s'étant signalés en particulier pour l'humectation des sols de la zone à humidité abondante et déficitaire. Ainsi, dans le premier cas, après un plafond quelconque d'humectation du sol, autour de 600—700 mm/an, l'écoulement superficiel (Y_0) augmente rapidement. Dans la zone à humidité déficitaire, au contraire, c'est l'évapo-transpiration qui augmente parallèlement à l'accroissement du degré d'aridité, jusqu'au taux de plus de 90% des précipitations tombées.

Dans la R.P.R. on observe une zonalité verticale classique dans la région carpatique, où l'humidité générale augmente avec l'altitude. En même temps, du fait que l'activité des cyclones se développe en direction ouest-est depuis l'Océan Atlantique, et que le sud-ouest du pays est affecté aussi par des cyclones provenant de la Mer Méditerrannée, les versants ouest et sud de l'édifice montagneux carpatique sont plus humides que les versants opposés, orientés vers des zones protégées. Ce rôle de protection des montagnes se reflète aussi dans les régions basses, à cause du processus catabathique pseudofphoenique, qui s'y observe en permanence.

Ces lois naturelles se reflètent bien dans le rapport entre K_w et l'altitude moyenne des bassins hydrographiques et dans les cartes des isolignes K_w (fig. 1 et 2). Ainsi K_w dans les régions de montagne a des valeurs baissantes descendant à de hautes altitudes jusqu'à 40—50%, tandis que dans les régions arides des plaines K_w approche les 100%, donc $W_0 \to X_0$.
En même temps, à cause de l'humectation différente des versants ouest, sud et de ceux d'est, le rapport avec l'altitude de l'indice K_w dans les divers districts montre des gradients différents.

Ces aspects se précisent si on étudie les lois de la répartition térritoriale des composants W_0, c'est à dire de l'évapo-transpiration et des infiltrations vers les eaux souterraines-U_0, qui dans les montagnes varient en sens opposé à l'évapo-transpiration.

L'évapo-transpiration diminue continuellement dans les Carpates, avec l'altitude, à cause de la diminution du bilan radiatif et de l'évaporabilité. On observe aussi une diminution de l'évapo-transpiration dans la direction des plaines du sud-est vers un axe imaginaire de l'évaporation maximum, qui s'étend au pied des montagnes. Dans la plaine ouestique cet axe est situé plus bas.

La question se pose, quelle est la cause de la présence de cet axe?

La réponse est relativement simple: dans cette zone d'altitude il existe une coïncidence entre l'évaporabilité et les précipitations relativement croissantes. Vers la Plaine Roumaine et vers la Dobrogea, bien que l'évaporabilité augmente, les précipitations diminuent, ne répondant pas aux possibilités de l'évaporation. C'est le signe le plus évident de l'aridité du climat, souligné par la présence du chernozem.

Dans la Plaine Ouest, dans des conditions d'évaporabilité accrue (plus de 700 mm), les précipitations sont relativement abondantes (600—700 mm), donc l'axe de l'évapo-transpiration maximum se déplace dans la plaine. La valeur de l'évapo-transpiration sur l'axe ouest se situe autour de 600 mm, et à l'est des Carpates à 530—560 mm. À partir de cet axe, les valeurs diminuent jusqu'à 200—250 mm, aux altitudes de 2 300—2 500 m et jusqu'à 500 mm dans la Plaine Ouest. Sur le Bărăgan et en Dobrogea la diminution de l'évapo-transpiration est plus accentuée à cause de l'aridité, allant jusqu'à 350 mm.

Les infiltrations vers la nappe phréatique (U_0) ont une variabilité territoriale plus grande. Dans les régions de plaines à loess du Bărăgan, celles-ci atteignent presque 5 mm, mais se montent vers les zones piémontanes à 20—50 mm. et dans les montagnes, à de hautes altitudes, jusqu'à

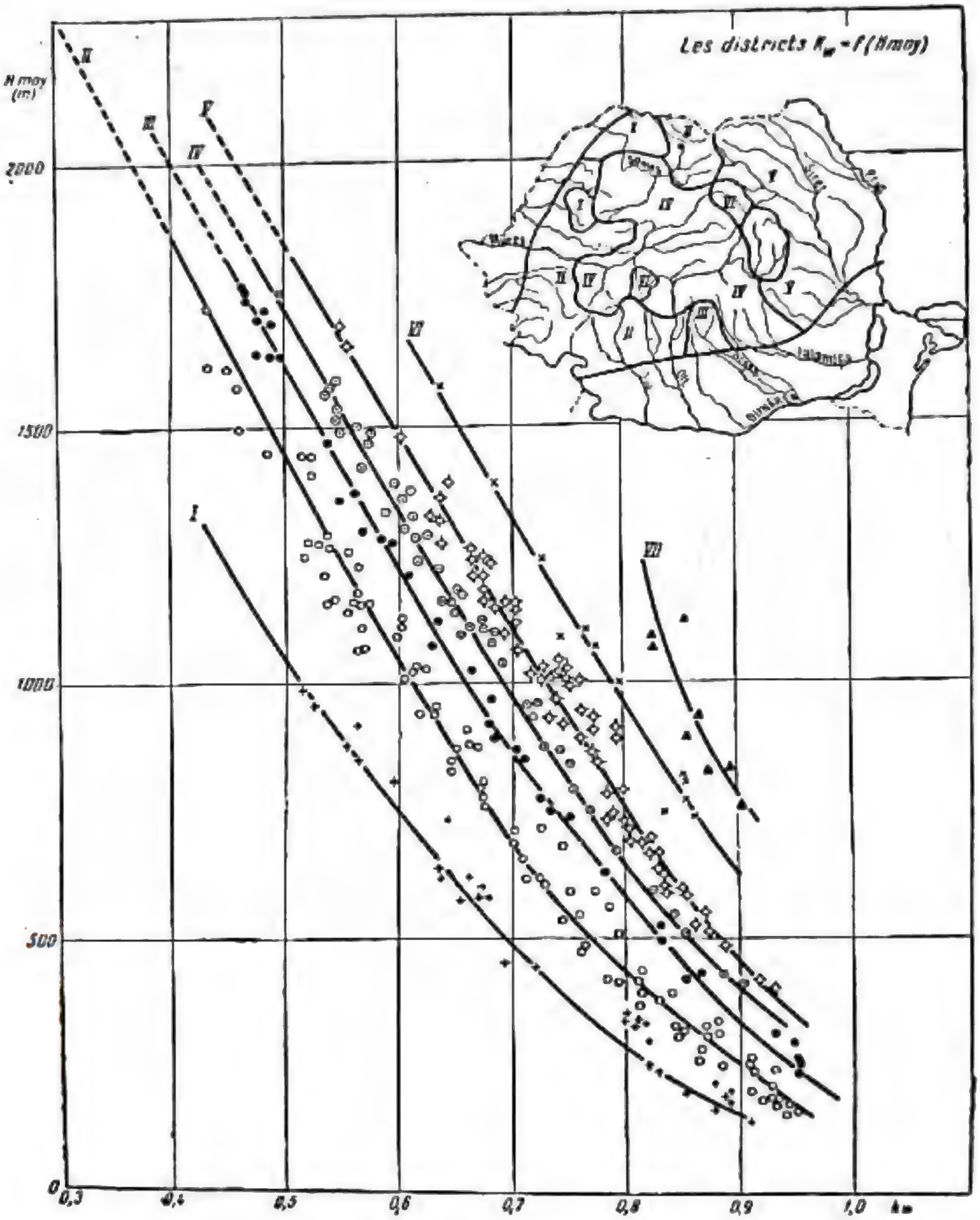

Fig. 1. Relations entre l'indice K_w et l'altitude pour différents districts.

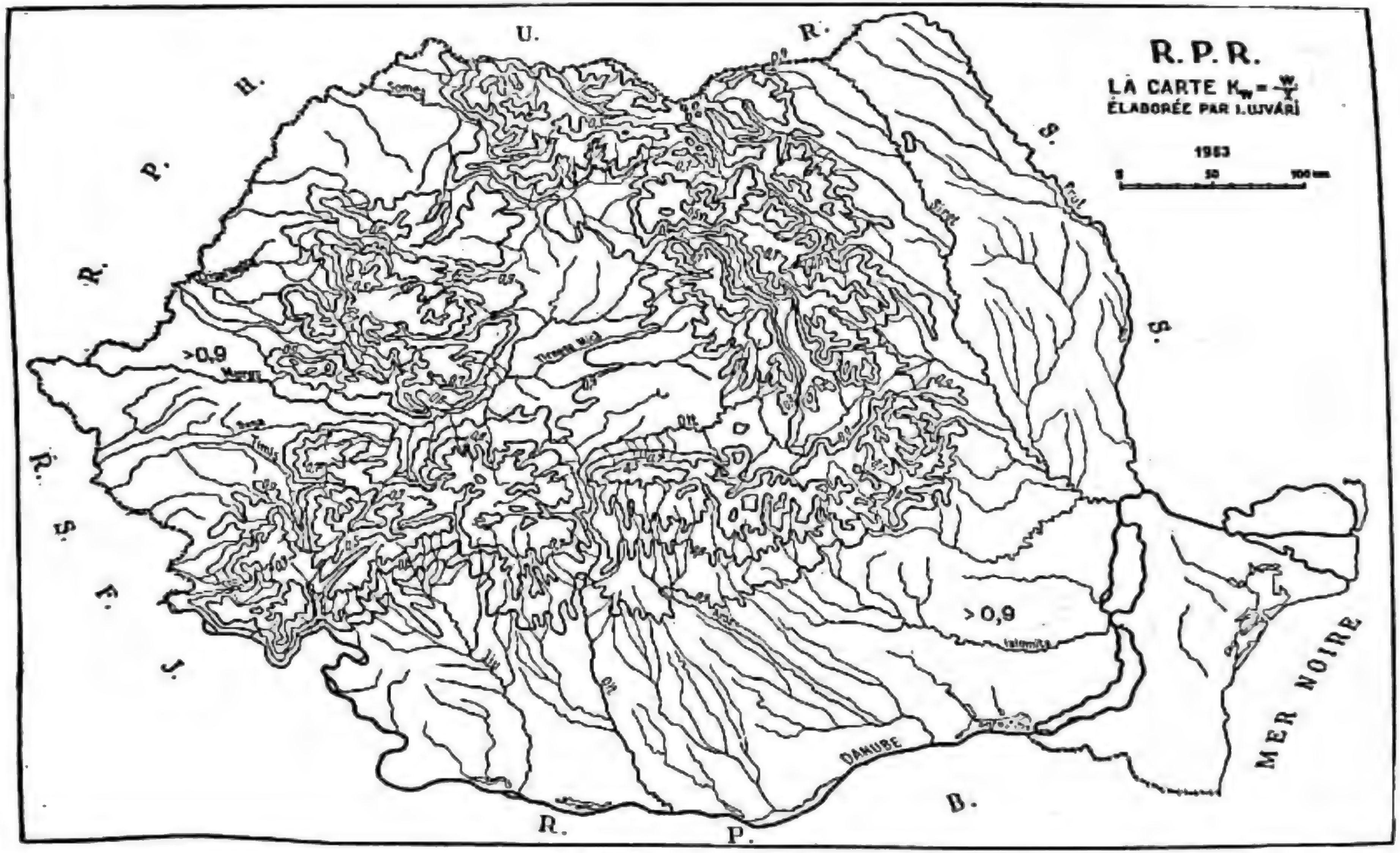

Fig. 2. Carte des indices K_w.

300—500 mm. Cette augmentation des infiltrations est due à l'intensification du changement de réserves des eaux souterraines parallèlement à l'augmentation de l'humidité du climat et de la déclivité des versants. L'intensification du drainage avec l'altitude se reflète aussi dans la présence des sols érodés.

Toutes les observations nous indiquent l'existence d'une circulation plus intense sur les pentes ouest plus humectées où, aux mêmes altitudes, U_0 atteint parfois le double de celui des pentes à exposition est.

L'humectation totale des sols (W_0) est l'un des composants les moins variables du territoire du bilan hydrologique. Cette constatation est valable avant tout pour les régions des Carpates situées dans les conditions d'une humidité abondante, où ses valeurs restent entre les limites de 600—700 mm/an. Les gradients des valeurs W_0 varient entre 2 et 10 mm/100 m/alt., étant plus élevés sur les pentes ouest des Carpates (les courbes et les rayons IV, V, VI de la fig. 3), que sur les pentes protégées (I, II).Cette différence est due aux valeurs plus élévées de l'évapo-transpiration dans les zones à processus catabathiques fréquents (chauffage catabathique dans la région de descente des masses d'air) et en même temps à la circulation plus lente des eaux souterraines (U_0 —à valeurs plus basses).

Comme l'on peut observer dans la figure 4, dans les régions de plaine, W_0 suit dans l'ensemble la configuration des isohyètes, parce que, entre elles, la différence n'est pas si grande (Y_r), et diminue avec l'intensification de l'aridité. En tout cas, on relève de grandes différences entre les valeurs W_0 dans la Plaine Ouest, la Plaine Roumanie et la Dobrogea.

LA VALEUR W_0 PAR RAPPORT AUX DIFFÉRENTS TYPES DE SOL DE LA ROUMANIE

Le régime hydrologique joue un role importante, bien connu, dans l'évolution des sols. En comparant la carte W_0 avec la carte des sols de la R.P.R., on peut observer une importante coïncidence au niveau des unités taxonomiques supérieures (zones, provinces). Ainsi, l'isoligne W_0—600 mm, délimite les sols de montagne des sols péricarpatique, à l'exception de ceux de la plaine et des piémonts ouest, où elle descend jusqu'à la limite des plaines de Salonta, de Lipova et de Gătaia. Par suite de l'humectation abondante des sols en ces districts, la nappe phréatique se trouve à basse profondeur et les sols humiques à gley apparaissent dans la zone des sols sylvestres bruns.

Dans le bassin de Transylvanie, dont le milieu général est représenté par les sols sylvestres bruns, apparaissent d'une manière isolée les chernozems lévigués. Cette île coïncide dans l'ensemble avec la zone de protection climatique située à l'est des Carpates Occidentales, où l'humectation totale des sols descend au-dessous de 550 mm. En ses grandes lignes la situation est la même dans le cas des piémonts sud, mais la diminution de l'humectation y suit la zonalité verticale habituelle.

Les chernozems sont répandus entre le isolignes 400 et 500 mm avec l'apparition dans quelques districts des chernozems lévigués.

Les chernozems calcaires sont répandus dans deux zones:

a) où l'humectation totale des sols diminue sous 400—420 mm;

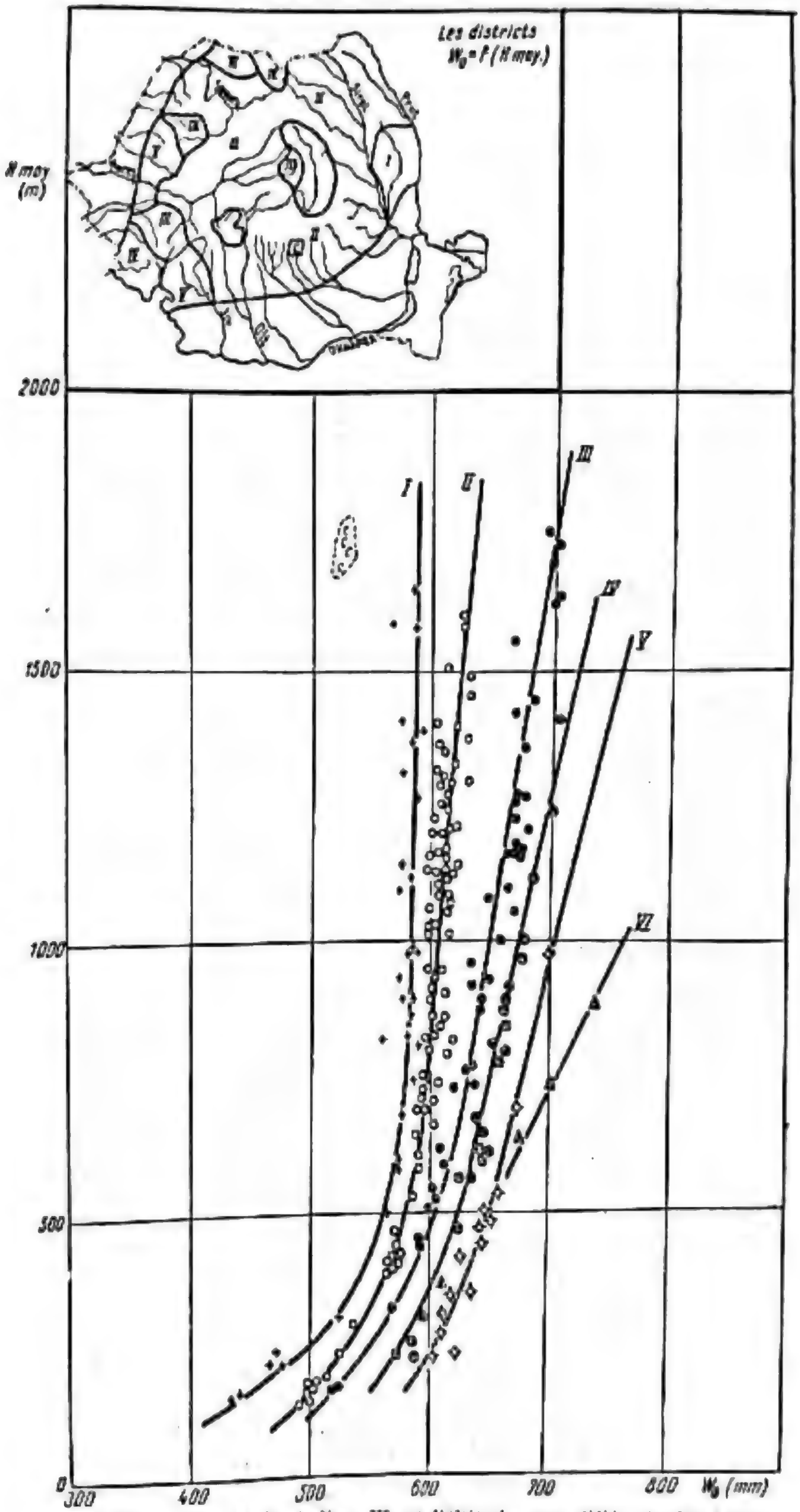

Fig. 3. Relations entre les indices W_0 et l'altitude pour différents districts.

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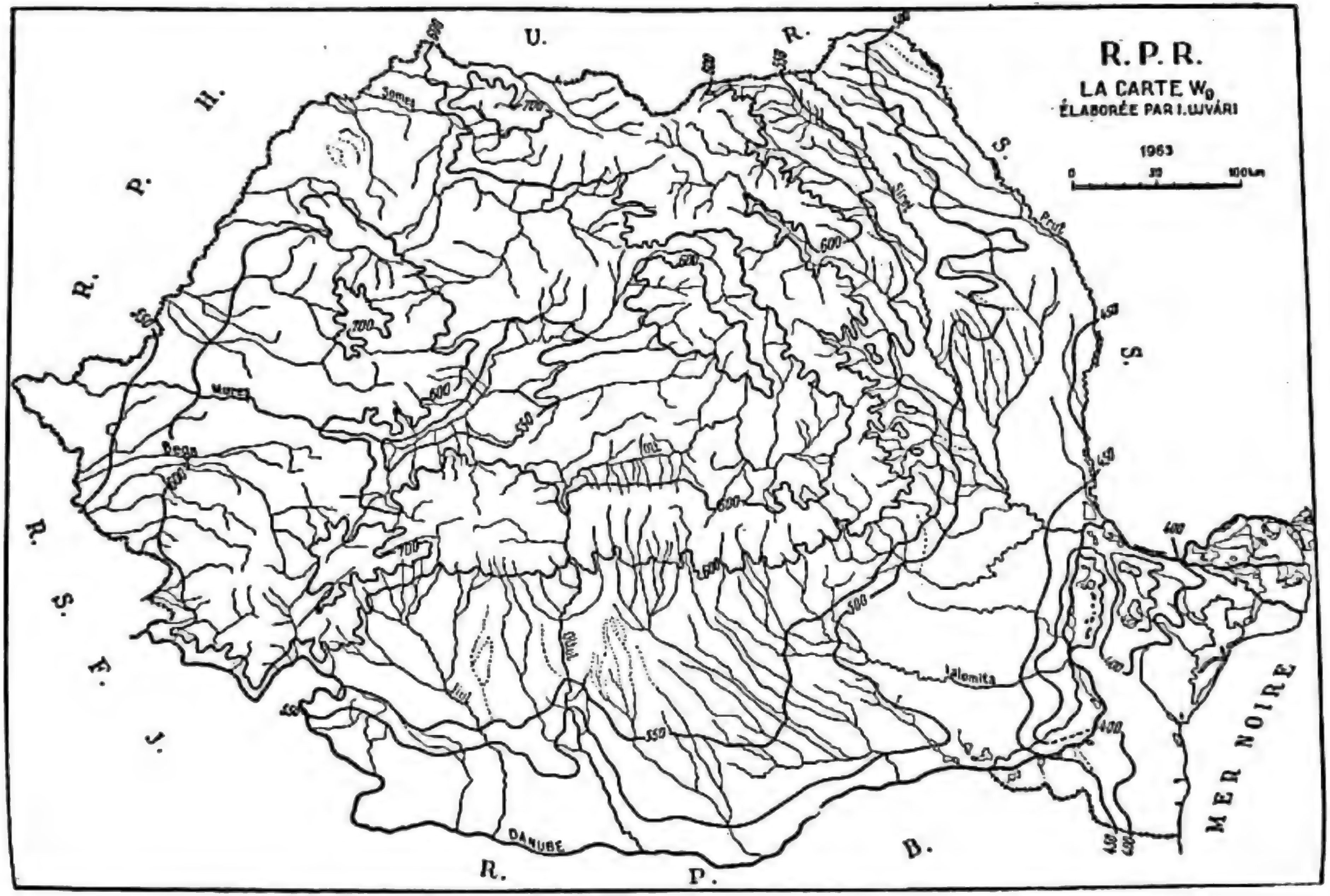
R.P.R.
LA CARTE W_0
ÉLABORÉE PAR I. UJVÁRI
1963
0
50
100 km
U.
R.
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R.
P.
H.
R.
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F.
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R.
P.
B.
MER NOIRE
DANUBE
Somes
Mures
Bega
Siret
Prut
Ialomita
Olt
Jiul
700
600
550
500
450
400

b) dans les règions semiendorćique (avec absence d'écoulement superficiel dans le Bărăgan), à humectation totale des sols de 400 à 480 mm.

Les particularités du bilan hydrologique dans les zones et secteurs délimités sur la carte des démarcations pédologiques districtuelles de Cernesco, Fridland et Florea (*Monografia geografică a R.P.R.*, 1960) peuvent être suivies plus bas:

$W_0 = 600$—780 mm
$Z_0 = 200$—600 mm
$U_0 = 50$—500 mm

Région des montagnes et des hautes collines.

a. La zone sols de prés alpins et sous alpins.
b. La zone avec prédominance des sols sylvestres bruns acides de montagne et sylvestres bruns acides de montagne podzoliques.
c. La zone de prédominance des sols sylvestres bruns de montagne et sylvestres bruns de montagne podzoliques.

Zone des sols sylvestres bruns

a. Secteur des dépressions submontanes Oaş-Baia Mare, Lăpuş, Maramureş.
b. Secteur collinaire Vad-Beiuş-Zarand.
c. Secteur collinaire Oraviţa-Lipova.
d. Secteur de la Plaine Gătaia.

$W_0 = 550$—600 mm
$Z_0 = 520$—580 mm
$U_0 = 20$—70 mm

Zone des sols sylvestres bruns

a. Secteur collinaire Silvaniei.
b. Secteur collinaire Someşelor.
c. Secteur collinaire Niraj-Someş.
d. Secteur submontan Cluj-Turda.
e. Le plateau des Tîrnave.
f. Secteur des dépressions submontanes Bîrsei, Făgăraş, Sibiu etc.
g. Secteur du Plateau Mehedinţi.
h. Secteur Motru-Argeş (piémont).
i. Secteur Argeş-Prahova.
j. Secteur subcarpatique Teleajen-Buzău.
k. Secteur de la Plaine Piteşti.
l. Secteur des dépressions submontanes.. (Tg. Jiu etc.).
m. Secteur du Plateau Suceava-Rădăuţi.
n. Secteur du Plateau Paşcani-Roman.
o. Secteur subcarpatique Bistriţa-Zăbrăuţi.
p. Secteur subcarpatique Rîmnic-Putna.

Zone des sols de chernozems lévigués

a. Secteur de la Plaine Arad-Salonta.
b. Secteur de la Plaine Pecica.
c. Secteur de la Plaine Sînicolaul Mare-Jimbolia.

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$W_0 = 500—550$ mm
$Z_0 = 490—530$ mm
$U_0 = 10—30$ mm

Zone de sylvo-steppe avec des sols de chernozems et des sols sylvestres bruns
a. Secteur de la Plaine de Transylvanie.
b. Secteur du Plateau Secaşelor.
c. Secteur Măcin.

Zone des sols sylvestres brun-roux

a. Secteur de la Plaine Craiova-Roşiori.
b. Secteur de la Plaine Bucureşti-Ploieşti.

Zone des chernozems lévigués

a. Secteur de la Plaine de Curtici.
b. Secteur de la Plaine Vinga.
c. Secteur de la Plaine Sînicolaul Mare.
d. Secteur de la Plaine Ialomiţa-Mostiştea

$W_0 = 450—500$ mm
$Z_0 = 440—490$ mm
$U_0 = 5—15$ mm

Zone des chernozems lévigués
a. Secteur Jijia-Bahlui-Ruginoasa.
b. Secteur Jijia-Başeu.
c. Secteur sud-est du plateau Bîrlad.
d. Secteur de la Plaine Tecuci.
e. Secteur de la Plaine Covurlui.
f. Secteur de la Plaine Segarcea.
g. Secteur de la Plaine Alexandria.
h. Secteur de la Plaine subcollinaire Mizil-Focşani.
i. Secteur Ostrov-Băneasa du Plateau Dobrogea.

Zone des chernozems

a. Secteur de la Plaine de Slobozia.
b. Secteur de la Plaine Pogoanele-Boldu.
c. Secteur de la Plaine Calafat-Corabia.
d. Secteur de la Plaine Zimnicea.

$W_0 = 400—450$ mm
$Z_0 = 400—440$ mm
$U_0 = 3—10$ mm

Zone des chernozems lévigués
a. Secteur de la Dobrogea du Sud.
b. Secteur de la Dobrogea du Nord.

La subzone des chernozems châtains
a. Secteur de la Plaine Jegălia.
b. Secteur de la Plaine Cioara-Galaţi.
c. Secteur Fălciu.

$W_0 = 350—400$ mm
$Z_0 = 350—395$ mm
$U_0 = 0—5$ mm

La subzone des chernozems calcaires
a. Secteur de la Plaine Feteşti-Brăila.
b. Secteur du Plateau Cernavoda-Măcin.
c. Secteur Mamaia-Istria.
d. Secteur Ceamurlia-Mahmudia.

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RÉSUMÉ

L'humectation totale du sol (W_0 mm) est considérée comme la somme de l'évapo-transpiration Z_0 et de l'eau d'infiltration qui alimente la nappe phréatique (U_0). Ainsi W_0 est la source de l'eau qui est disponible pour la végétation. Elle varie entre 600—780 mm dans la zone à humidité des Carpates roumaines, diminuant jusqu'à 350 mm, dans les régions arides.

On analyse les lois naturelles de la répartition territoriale de W_0 et son rapport avec les zones et les secteurs des sols de Roumanie. On analyse aussi le coefficient d'humectation totale du sol, qui représente le rapport entre W_0 et les précipitations moyennes.

SUMMARY

The total wetting of the soil (W_0 mm.) is considered as the sum of evapo-transpiration (Z_0) and of infiltration water supplying the ground water (U_0). Thus, W_0 is the available water source for vegetation. It varies between 600 and 780 mm in the more humid region of the Rumanian Carpathes, decreasing up to 350 mm. in the dry regions.

The natural law of the territorial repartition of W_0 and its relations to the soil zones and districts of the Romanian People's Republic are analysed.

The total wetting coefficient of the soil, representing the relation between W_0 and the average rainfall, is also analysed.

ZUSAMMENFASSUNG

Die Gesamtbefeuchtung des Bodens (W_0 mm) wird als die Gesamtsumme der Evapotranspiration (Z_0) und des Einsickerungswassers, welches die Grundwasser (U_0) speisen, betrachtet. Demzufolge ist W_0 die Quelle des für die Pflanzenwelt verfügbaren Wassers. Es schwankt zwischen 600—780 mm in der feuchtigkeitsreichen Zone der rumänischen Karpaten, und sinkt bis zu 350 mm in den trockeneren Gegenden.

Im Beitrag werden die natürlichen Gesetze der Gebietsverteilung des W_0 und sein Zusammenhang mit den Bodenzonen und -teilgebieten in Rumänien analysiert. Es wird auch der Gesamtbefeuchtungskoeffizient des Bodens erörtert, der das Verhältnis zwischen W_0 und den durchschnittlichen Niederschlägen darstellt.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

INFLUENCE OF CROPS ON SOIL MOISTURE DYNAMICS IN A STEPPE ZONE

H. SIMOTA [1]

Studies on moisture dynamics presents a peculiar importance for a better agricultural knowledge of different soils. This is due to the fact that knowing it, one may consciously intervene, by modern technical means, in the management of production. This is especially necessary in steppe zones with moisture deficiency, where differential management practices aim at accumulating and preserving water to as great an extent as possible.

In soil science literature moisture dynamics is often considered as a property of the soil. Moisture content values obtained as an average for many years are in fact suited to determine the properties of the studied soil. Following this approach, crops cultivated in the respective soil are not considered to impose substantial modifications in the soil moisture dynamics, even up to the penetration depth of the roots, moisture dynamics depending only on climatic conditions.

Researches were carried out in the steppe zone, on the chestnut chernozem of the Bărăgan (Mărculeşti, Bucharest region), during a three years period from 1953—1956, in order to check up if the cultivated crops exert or not some influence on soil moisture dynamics in such zones. For this purpose, soil moisture content was determined for layers each 10 cm deep, up to the depth of 150 cm, with a periodicity of 15 days. The water properties of this soil, with a loamy texture, developed on loess, having an *A* horizon with a depth up to 54 cm, a transition horizon *A/C* from 54 to 89 cm and a calcium carbonate accumulation horizon *C* from 89 to 119 cm, are shown in table 1.

In order to simplify the presentation of the numerous results, the monthly averages for genetical soil horizons, expressed in percentage of field capacity, are used. This brings us nearer, as much as possible, to an agricultural interpretation of soil moisture, as well as to a possibility of comparison with other soil types.

During the experimental period, three main problems were examined:

1) moisture dynamics in a soil cultivated with various crops during the vegetation period;

2) influence of the previous crop on the moisture dynamics;

3) moisture dynamics proper to different soil tillage systems.

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Table 1

Water properties of the chestnut chernozem of Mărculeşti

Horizon	Density	Bulk density	Maximum adsorption capacity	Maximum hygroscopic coefficient	Wilting range: plant death	Wilting range: wilting begining	Field capacity
A_a	2.45	1.05	3.98	6.49	4.87	9.76	27.85
A_m	2.50	1.15	3.76	6.20	4.71	9.33	25.33
A/C	2.54	1.21	3.19	5.22	4.20	8.73	23.84
C	2.56	1.25	2.66	4.46	3.59	7.93	21.31
D	2.58	1.28	2.34	3.89	3.19	6.86	19.65

MOISTURE DYNAMICS IN A SOIL CULTIVATED WITH VARIOUS CROPS DURING THE VEGETATION PERIOD

The moisture dynamics of a soil cultivated with pea, oats, maize, sunflower, wheat and perennial grasses was examined. The results during the vegetation period of each plant are presented in fig. 1—6, which show dynamically the monthly averages obtained for each soil horizon. The average hydric soil profile during the vegetation period of each crop was also calculated and is shown in table 2.

Table 2

The average hydric profile (per cent of field capacity) under various crops during their vegetation period

Horizon	Pea	Maize	Oats	Sunflower	Wheat	Perennial grasses: first year	Perennial grasses: second year
A_a	80.29	67.55	70.44	67.75	83.91	59.97	78.62
A_m	86.73	75.08	79.89	75.48	79.56	68.31	76.45
A/C	86.61	78.50	79.88	76.14	70.83	69.38	64.62
C	94.32	81.97	78.39	77.47	65.51	70.03	57.56
D	93.92	80.41	69.19	67.47	61.39	67.18	49.96
Average	88.39	76.70	75.55	72.86	72.24	66.97	65.44

The highest average hydric profile (88 per cent of field capacity) was recorded for pea. In March, the water reserve was > 90 per cent in the *A* horizon, 80—90 per cent in the *A/C* and *C* horizons and 70—80 per cent in the *D* horizon. In each horizon, moisture increases until May, exceeding 90 per cent on the whole profile. In June, moisture decreases up to 70—75 per cent in the *A* and *A/C* horizons and up to 80—90 per cent in the *C* and *D* horizons, showing a continuous moisture increase in the deeper layers (fig. 1).

The average hydric profile for oats equals 75 per cent. In March, moisture was 80—90 per cent in the *A* and *A/C* horizons and 55 per cent in the *C* and *D* horizons. Water content increases until April in the *A* and *A/C* horizons (90—95 per cent), then decreases gradually. In July, it reaches 65—75 per cent in the *A* horizon and 50—55 per cent in the other ones. Opposite the soil cultivated with pea, for oats there is a significant decrease in moisture in the lower layer (fig. 2).

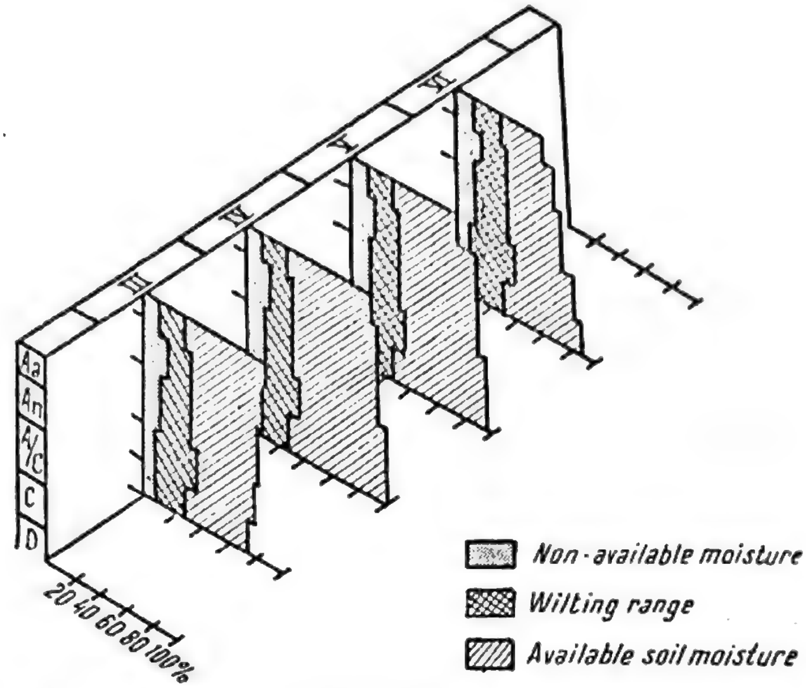


Fig. 1. Soil moisture dynamics of the chestnut chernozem during the vegetation period of pea (in per cent of field capacity).

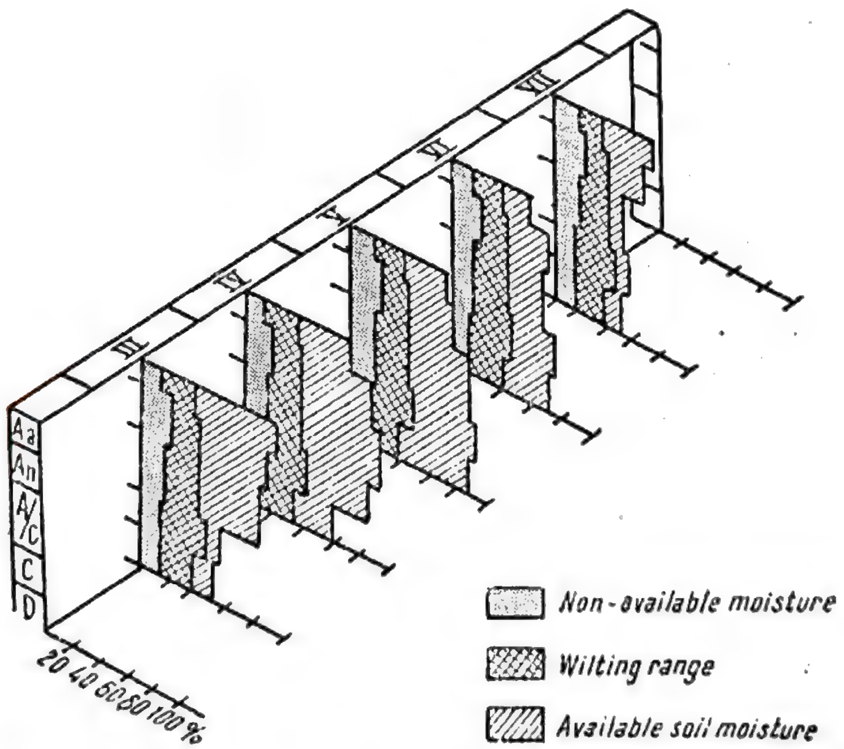


Fig. 2. Soil moisture dynamics of the chestnut chernozem during the vegetation period of oats (in per cent of field capacity).

Maize shows an average hydric profile of 76 per cent. In April, the profile moisture reaches >90 per cent, decreasing in June up to 80—90 per cent diminishing rapidly in September up to 40—45 per cent over the whole profile (fig.3).

Sunflower proved to have an average hydric profile equal to 72 per cent. In April the profile moisture is >90 per cent in A, A/C and C, and 50—55 per cent in D. In May, the D horizon moisture reaches 80—85 per cent, while the moisture of the upper horizons is unchanged (fig.4). The decrease in soil moisture in July-September is greater than for maize, the moisture for the A/C and C horizons being within the wilting range.

Winter wheat had an average hydric profile of 72 per cent. In October the moisture of the whole profile was 50—55 per cent, the increase beginning in November, and reaching in March 90—95 per cent in the A horizon, 80—85 per cent in the A/C horizons and 60—65 per cent in the C and D horizons. Until June, the moisture decreases to 70—75 per cent in the A horizon and 65—70 per cent in the C and D horizons, these values being inferior as compared to those for row crops or pea and superior to those for oats in the C and D horizons at the same data (fig.5).

Perennial grasses, in the first (fig. 6) as well as in the second (fig. 7) year of growth present the most unfavourable conditions from the point of view of soil moisture, the average hydric profile equaling 66 per cent for the first year and 65 per cent for the second year. In March, the profile moisture was more than 90 per cent in the A horizon, 80—90 per cent in the A/C horizon and 55—60 per cent in the C and D horizons, increasing in June up to 85—90 per cent in the A horizon and up to 90—95 per cent in the C horizon. During the following dry period the moisture reserves diminished to 30—35 per cent on the whole profile, in September all values being within the wilting range. The restauration of moisture reserves occurred in February for the A horizon, in March for the A/C horizon and in April for the C horizon. In July the profile moisture is 60—70 per cent for the whole profile, being in a constant decrease.

The results show that on the same soil, crops cultivated under identical climatic conditions grow and develop at different soil moisture. From this point of view, the best conditions showed to have the pea, whose hydric profile presented values ranging from 80 to 95 per cent with an important water storage in the lower C and D horizons. The most unfavourable conditions presented the perennial grasses, which besides the small average hydric profile, indicate also an exhaustion of the moisture storage from the lower horizons. The other plants, maize, oats, sunflower and wheat, range between these two extremes with the tendency to approach the pea (fig.8).

INFLUENCE OF THE PREVIOUS CROP ON MOISTURE DYNAMICS OF THE SAME PLANT

Soil moisture dynamics under wheat following falow, pea, maize and perennial grasses was investigated (table 3). The results obtained demonstrated that previous crops strongly influence the water supply of the follo-

Fig. 3. Soil moisture dynamics of the chestnut chernozem during the vegetation period of maize (in per cent of field capacity).

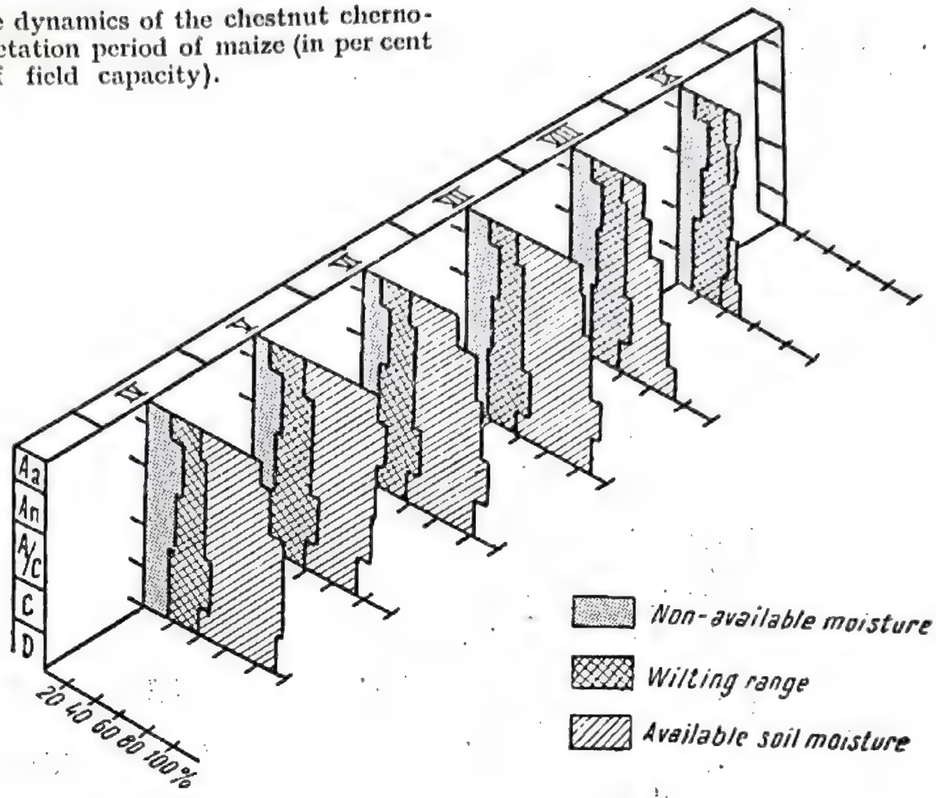


Fig. 4. Soil moisture dynamics of the chestnut chernozem during the vegetation period of sunflower (in per cent of field capacity).

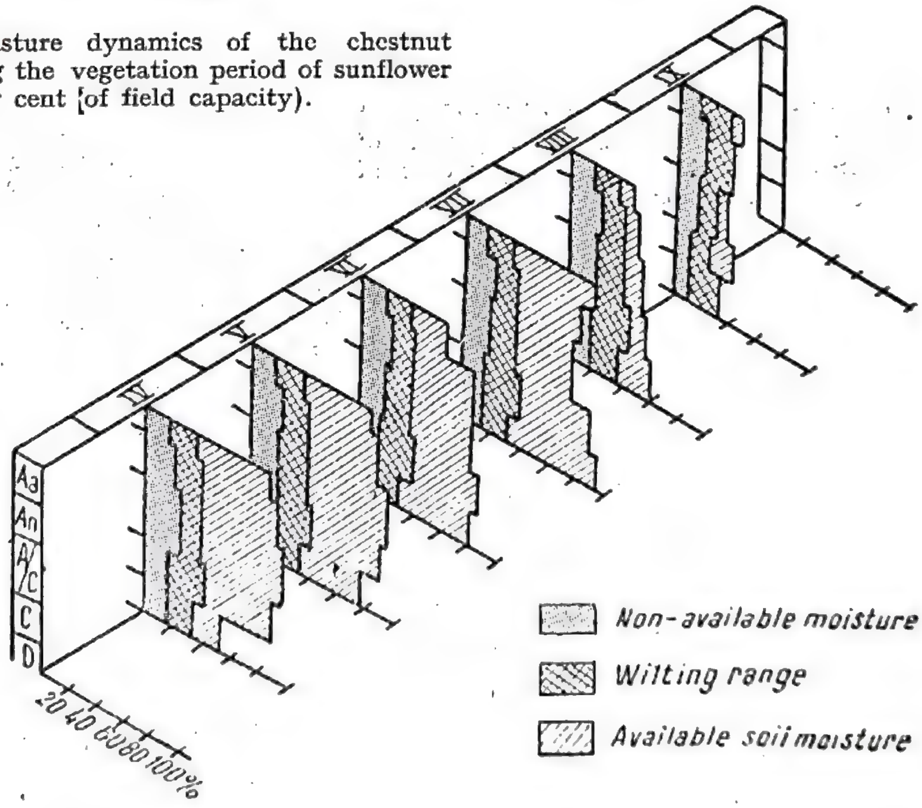


Fig. 5. Soil moisture dynamics of the chestnut chernozem during the vegetation period of winter wheat (in per cent of field capacity).

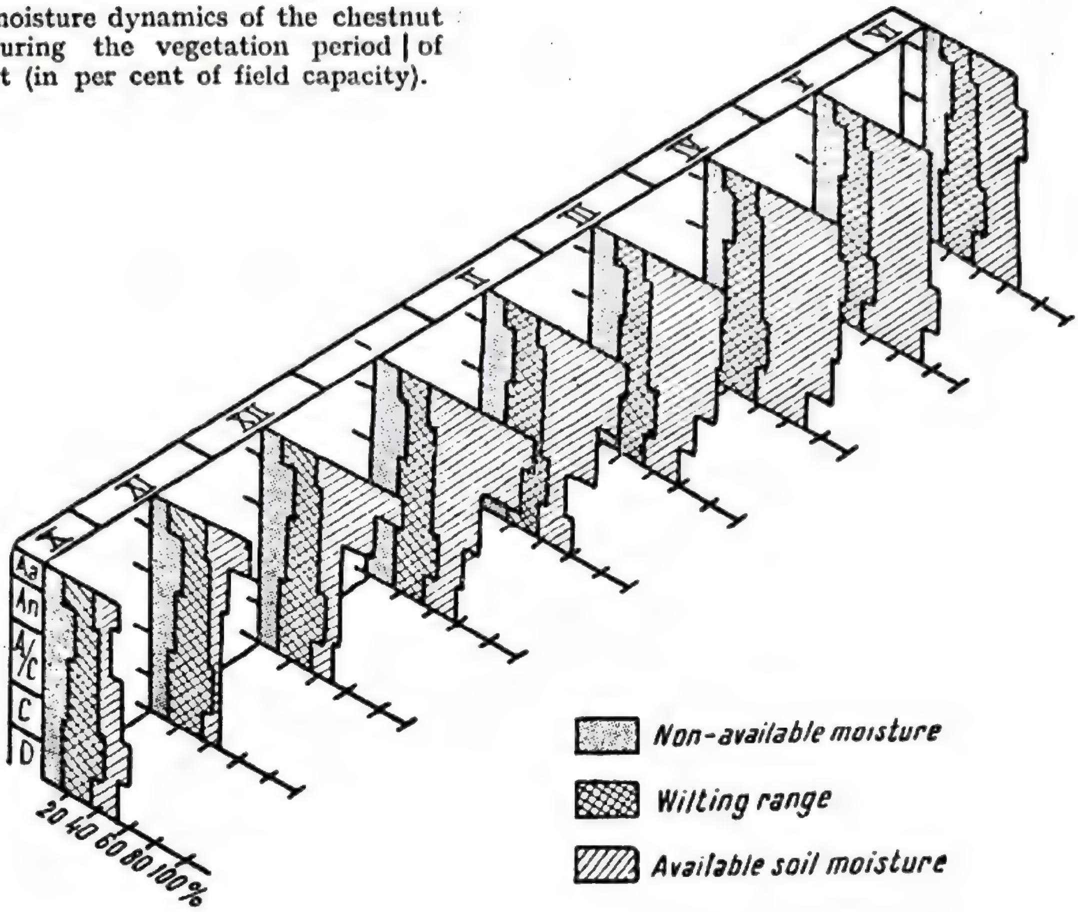


Fig. 6. Soil moisture dynamics of the chestnut chernozem during the vegetation period of perennial grasses (first year)(in per cent of field capacity).

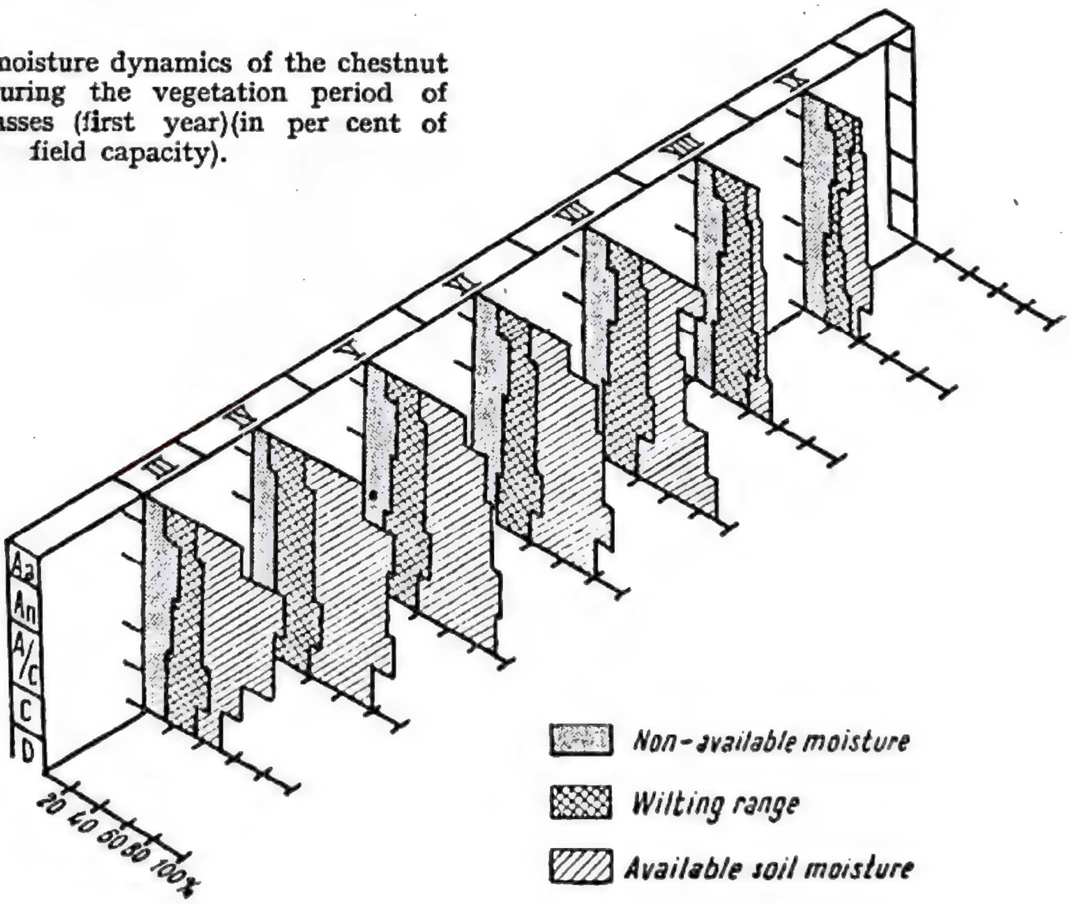


Fig. 7. Soil moisture dynamics of the chestnut chernozem during the vegetation period of perennial grasses (second year) (in per cent of field capacity).

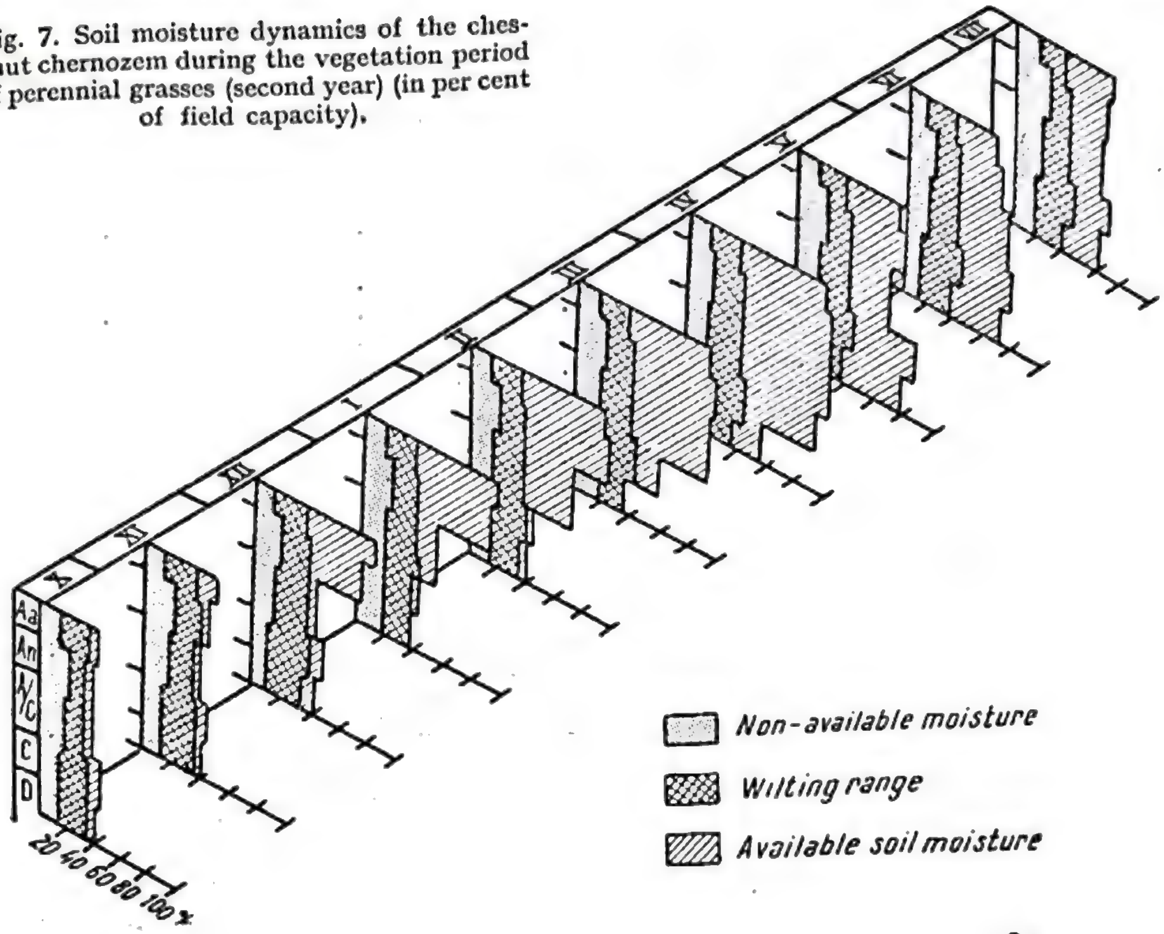


Fig. 8. Average hydric profile of the chestnut chernozem cultivated with various plants during the vegetation period (in per cent of field capacity).

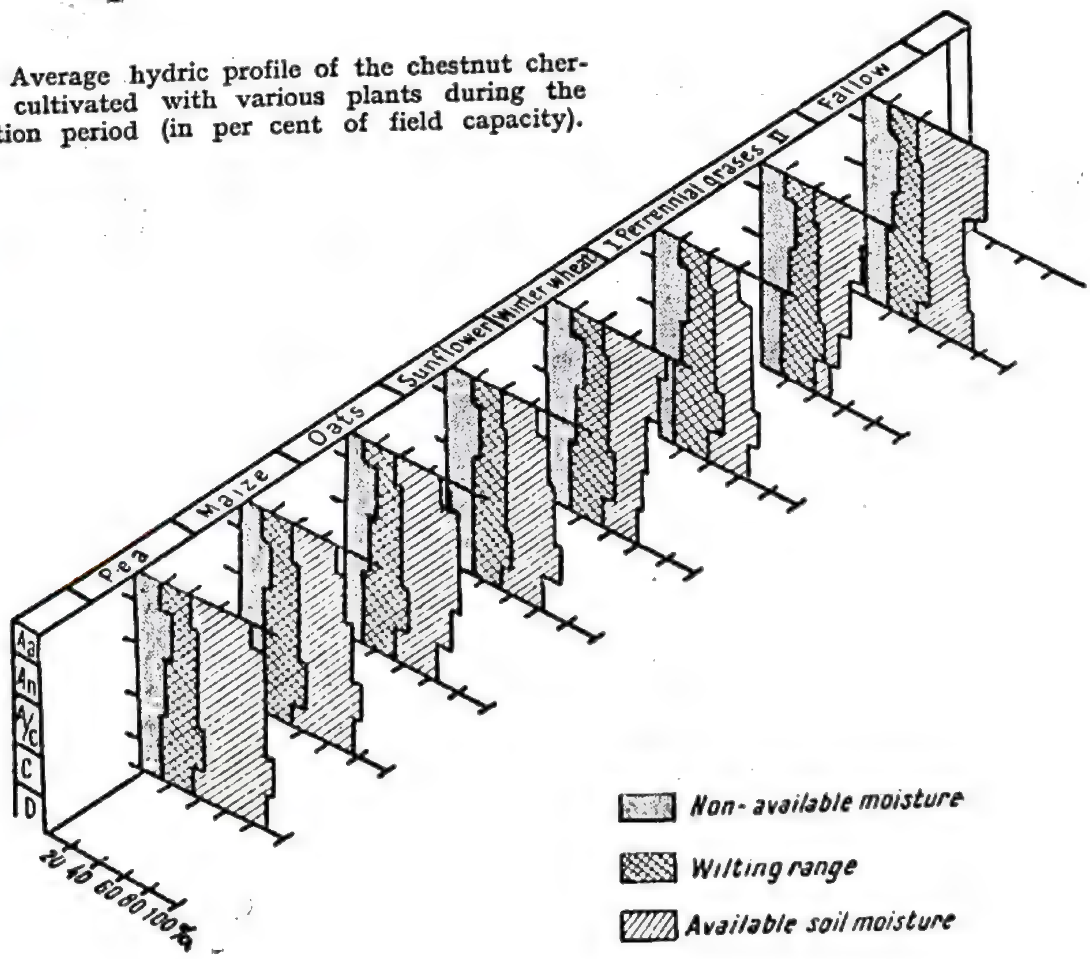


Table 3

Average hydric profile (per cent of field capacity) under wheat, as affected by the previous crop

Horizon	Previous crops			
	fallow	pea	maize	perennial grasses
A_a	90.16	82.72	83.32	79.48
A_n	89.09	76.31	78.95	73.89
A/C	86.14	68.10	67.75	60.83
C	86.54	64.44	61.24	49.82
D	86.41	62 66	54.34	42.37
Average	87.66	70.84	69.12	61.27

wing crop. For wheat the best water supply occurred after fallow (average hydric profile 88 per cent and the smallest after perennial grasses (61 per cent). Although after pea and maize the average hydric profile was alike (71 per cent and 69 per cent), in the lower horizons C and D the water storage was greater after pea, showing the importance of previous crops having a short period (half fallow crops).

Moisture graphs (fig. 9—12) point out that the greatest differences in soil water supply are to be found in autumn. In October, the soil moisture reserve was 35—40 per cent after perennial grasses, 45—50 per cent after maize, 40—50 per cent after pea and 70—74 after fallow. In March it reached 80—90 per cent (in the A and A/C horizons) and 45—50 per cent (in the C and D horizons) after perennial grasses; 80—90 per cent (in the A and A/C horizons), 60—65 per cent (in the C horizon) and 45 per cent (in the D horizon) after maize and pea; >90 per cent after fallow. At wheat harvest, the soil moisture amounts to 60—70 per cent on the whole profile, excepting the D horizon after grasses, which had only 50 per cent moisture.

CHARACTERISTIC MOISTURE DYNAMICS ACCORDING TO DIFFERENT SYSTEMS

Moisture dynamics was also investigated (after crops which are harvested early in summer as well as after crops which are harvested late in autumn) in the period preceeding the autumm and spring sowing. The average results are presented in table 4. As compared to the former results, an important

Table 4

Average hydric profile (in per cent of field capacity) in the period ranging from the harvest of previous crop to the seeding of the following crop

Harvest period of previous crop	Summer		Autumn	
Seeding period	Autumn	Spring	Autumn	Spring
A_a	35,63	72.17	49.22	89.83
A_n	39,03	63.95	42,66	78.60
A/C	43,23	50.81	44.73	63.40
C	49,53	48,28	46.94	52,36
D	49,20	53.15	48.30	52.66
Average	43,32	57,67	46,17	67.37

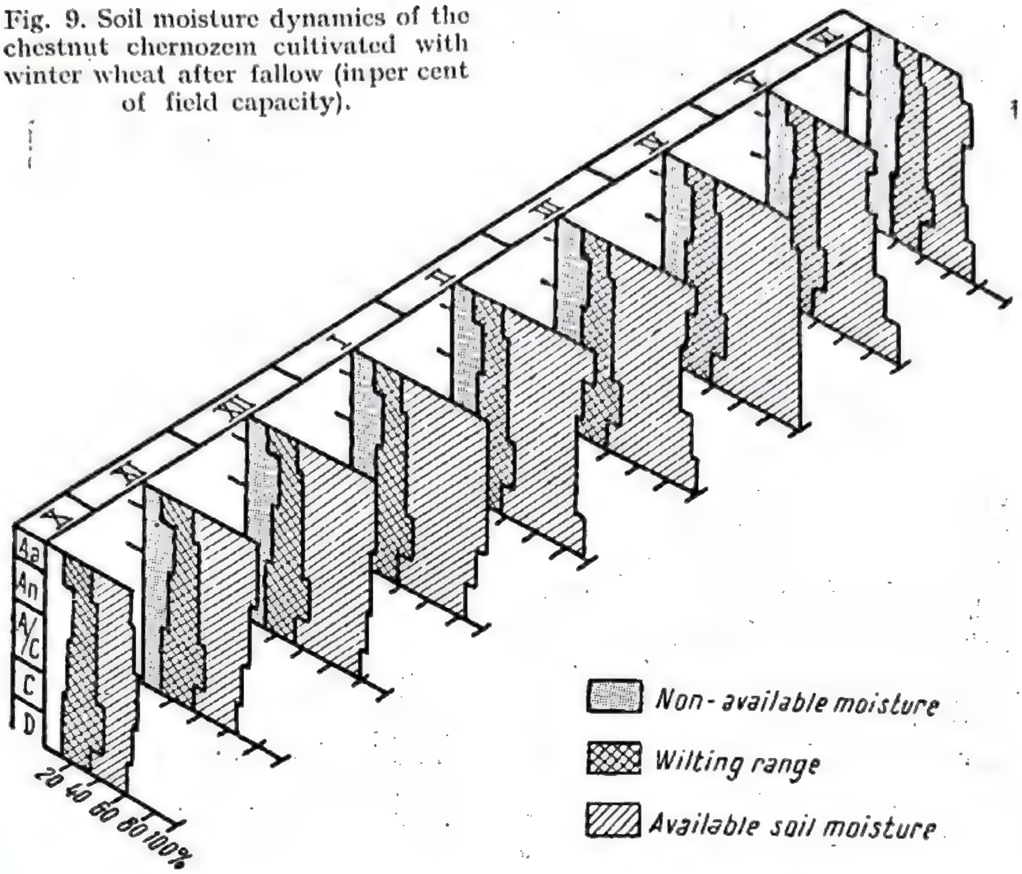


Fig. 9. Soil moisture dynamics of the chestnut chernozem cultivated with winter wheat after fallow (in per cent of field capacity).

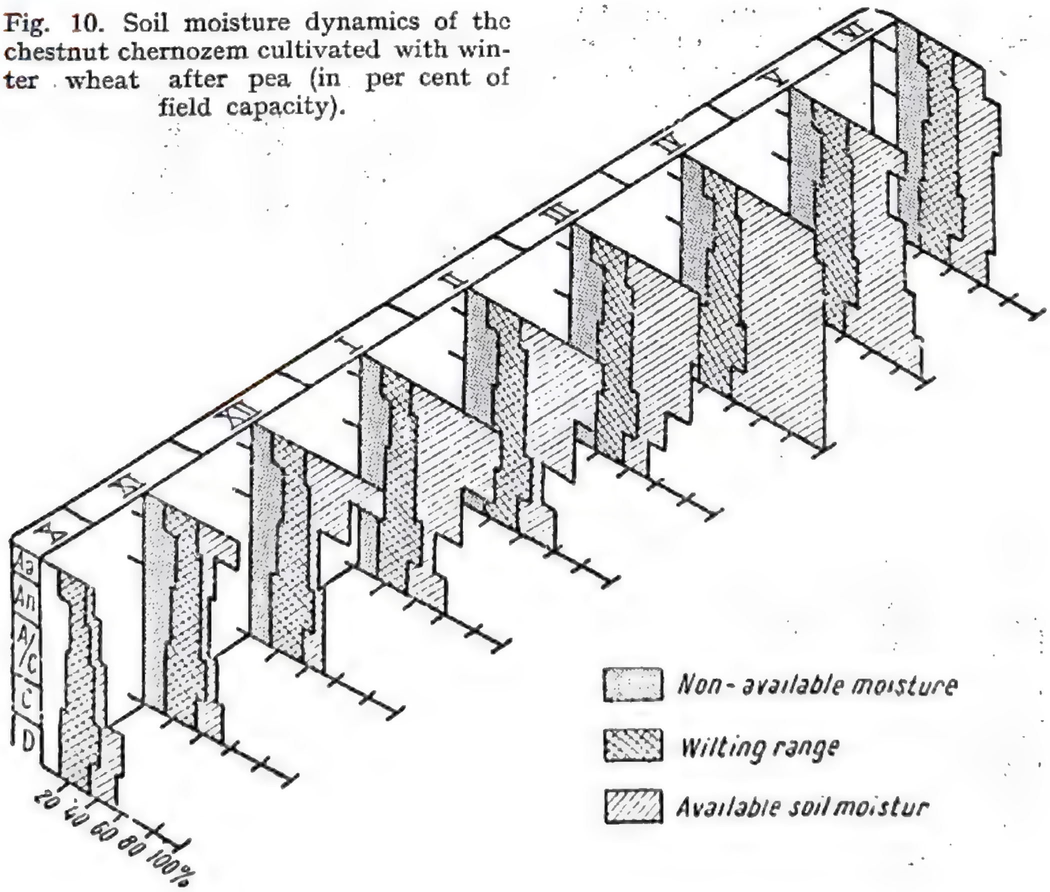


Fig. 10. Soil moisture dynamics of the chestnut chernozem cultivated with winter wheat after pea (in per cent of field capacity).

Fig. 11. Soil moisture dynamics of the chestnut chernozem cultivated with winter wheat after maize (in per cent of field capacity).

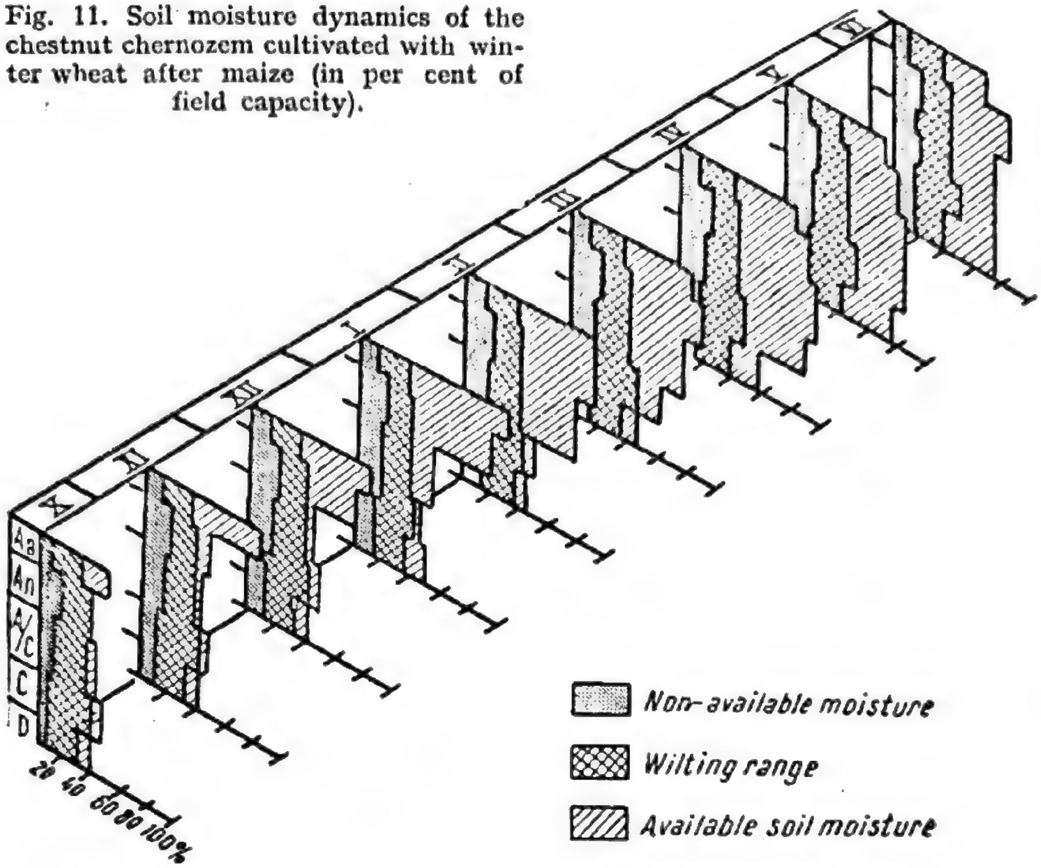
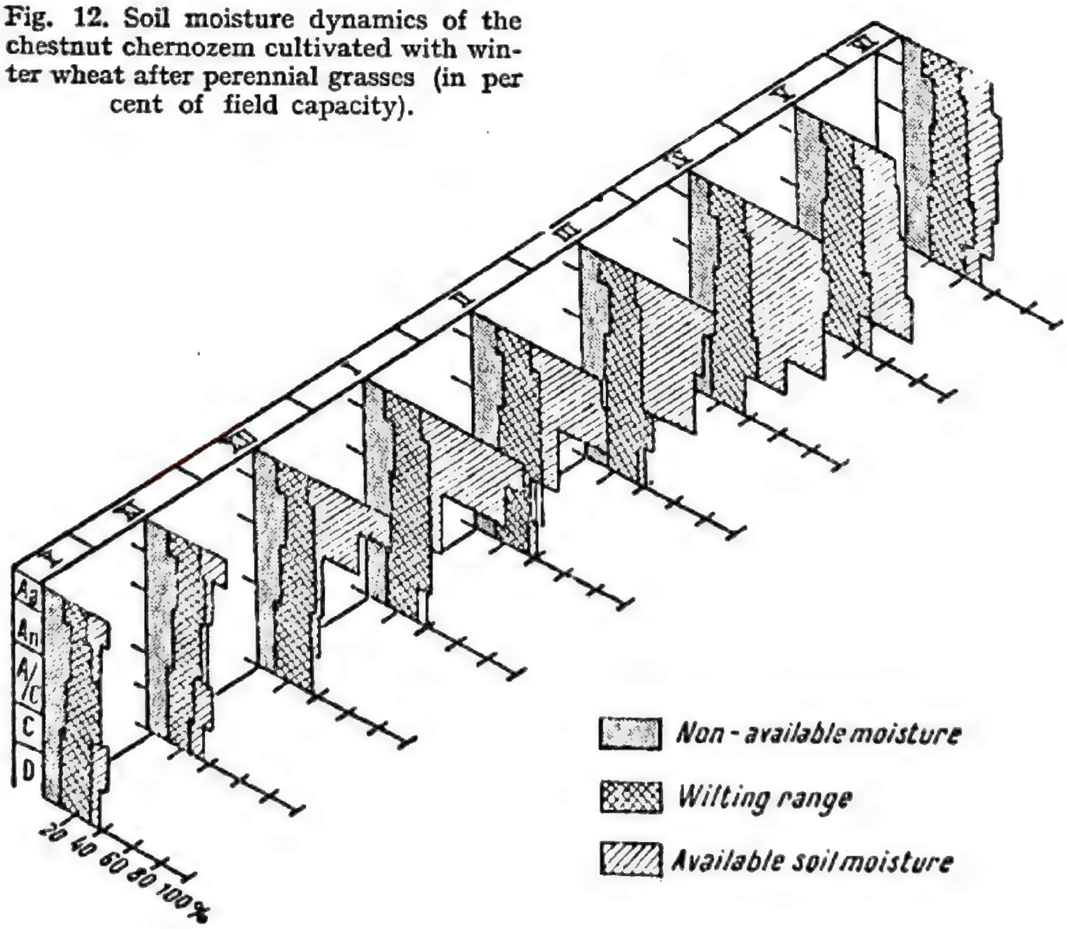


Fig. 12. Soil moisture dynamics of the chestnut chernozem cultivated with winter wheat after perennial grasses (in per cent of field capacity).



water loss occured in the period when the soil was uncovered by crops; these losses my be recovered only partially by the autumn and winter precipitations. Winter crops were sown under the lowest moisture conditions (35 per cent and 48 per cent in the A_a horizon). The spring crops were sown at a greater water content, especially when following crops harvested in autumm.

CONCLUSIONS

1. Under identical climatic conditions, the available moisture storage is greatly influenced by the soil management practices aiming at promoting soil water accumulation and storage.
2. In the frame of the natural process of soil moisture dynamics in steppe zones, quantitative differences were found between the cultivated plants. Crops with a short vegetation period show a good water supply, while crops which are harvested in autumn undergo a moisture deficiency during the second part of their vegetation period. The perennial grasses had the lowest moisture reserve, which decreased to the lowest limit of the wilting range on the whole profile.
3. Moisture dynamics of the soil cultivated with the same crop was different, depending on the previous crop. The best water supply was recorded after half fallow crops, the worst after crops with a long vegetation period. Even after a year of wheat cropping, following perennial grasses, the moisture storage in the lower horizons did not recover.
4. Differences were pointed out as regards soil water storage, depending on the tillage system. The smallest water supply of winter crops is to be noticed at their sowing period, even if they have followed crops harvested in summer or in autumn.

SUMMARY

Researches were carried out in the steppe zone, during a three year period, on moisture dynamics of a chestnut chernozem. The effect of different crops and soil management practices on the moisture of the soil horizons and on the average hydric profiles was pointed out.

RÉSUMÉ

On a poursuivi pendant 3 années dans la zone de steppe des recherches sur la dynamique de l'humidité d'un chernozem châtain. L'effet des différentes plantes cultivées et pratiques d'entretient du sol sur l'humidité des horizons du sol et sur le profil hydrique moyen est mis en relief.

ZUSAMMENFASSUNG

Es wurden während 3 Jahre in der Steppenzone Untersuchungen über die Feuchtigkeitsdynamik eines kastanienfarbigen Tschernosems unternommen. Es wird die Einwirkung verschiedener Kulturen und agrotechnischer Massnahmen auf die Feuchtigkeit der Bodenhorizonte und auf das mittlere hydrische Profil hervorgehoben.

DISCUSSIONS

F. F. R. KOENIGS (Netherlands). What is the influence of the previous crop on the yield of following wheat?

H. SIMOTA. Wheat yields depend on the quantity of soil water, which is different according to the previous plant. At the same rate of fertilizers, the greatest yield is obtained after fallow, immediately followed by wheat after pea, which in fact represents a half fallow. Wheat after maize follows. Smallest yields, less than 50 per cent of the most favourable treatment, is obtained after perennial grasses; this crop actually has no practical perspective in this zone; as it is exhausting the water storage of the deep soil layers.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 18

SOIL AIR COMPOSITION AND OXYGEN DIFFUSION RATE IN SOIL COLUMNS AT DIFFERENT HEIGHTS ABOVE A WATER TABLE

K. J. KRISTENSEN, H. ENOCH [1]

INTRODUCTION

Most cultivated plant species require in their rooting medium a certain oxygen concentration in order to maintain healthy root development, and for uptake of nutrient elements and water. From many practical and experimental experiences it is known that a stagnating ground water table near to the soil surface constitutes for most soils a barrier for root growth of most of the cultivated plant species. It is reasonable to assume that this restrictive effect is caused by lack of oxygen possibly combined with a high carbon dioxide content. One of the main purposes for draining waterlogged soils is to facilitate the aeration of the deeper soil layers, and thereby secure sufficient oxygen for a healthy growth and development of the plant roots.

In the following a brief description will be given of an experimental set-up for laboratory study of the change in soil aeration that occurs as a sagnating ground water table is approached. Also a cheap and convenient apparatus for analysis of micro-airsamples (about 0.005 cm^3) is described. The results obtained for three different soils are given and discussed.

TECHNIQUE AND APPARATUS

The investigations are carried out in the laboratory. The soils are air-dried and then passed through a sieve having 2 mm round holes. The cylinders holding the soil are made from plexiglass tubing having a 5.4 cm inside diameter. Each cylinder consists of ten pieces 5 cm in length assembled by rubber bands.

The experimental soils are introduced into the cylinders using a standardized procedure in order to obtain as uniform a packing as possible. The textural composition of the soils is given in table 1. The three soils will be designated below as I, II and III as in the table.

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Table 1

Textural composition of the experimental soil weight per cent of dry soil

Soil	Clay below 2 μ	Silt 2—20 μ	Fine sand 20—200 μ	Coarse sand 200—2000 μ	Organic matter
I	5.6	7.3	17.5	67.3	2.3
II	10.5	10.9	17.6	58.6	2.4
III	15.5	14.6	17.8	49.6	2.5

It is seen that the soils have nearly the same content of organic matter and fine sand, but differ in their content of clay, silt and coarse sand. The clay and silt content is increasing and coarse sand decreasing in the order from I to III.

The water content and bulk density of the different 5 cm sections as determined just after the completion of the experiment are given in table 2.

Table 2

Water content by volume and bulk density at 5 cm intervals

Sections of 5 cm (from top of column)	Soil I		Soil II		Soil III	
	Water per cent	Bulk density gm cm^{-3}	Water per cent	Bulk density gm cm^{-3}	Water per cent	Bulk density gm cm^{-3}
0—5	27.1	1.50	22.1	1.17	29.7	1.34
5—10	29.9	1.47	27.4	1.36	35.5	1.38
10—15	31.8	1.46	33.2	1.43	37.3	1.42
15—20	33.6	1.42	36.7	1.42	38.1	1.40
20—25	37.6	1.41	39.7	1.41	40.2	1.41
25—30	36.9	1.43	40.0	1.45	40.4	1.43
30—35	38.3	1.43	39.9	1.45	41.0	1.41
35—40	38.0	1.39	38.1	1.38	41.0	1.38
40—45	38.2	1.44	40.4	1.45	41.3	1.43

Except for soil II, 0—5 cm there seems to be a rather good uniformity in the columns, and also the volume weight in the different soils is nearly the same. The 0—5 cm section was only partly filled with soil and the determination was therefore uncertain.

The experimental set-up is shown in figure 1 A. In the middle of each section a hole is drilled in which a special rubber stopper (*a*) is inserted. This rubber stopper has a small hole in the center for mounting a diffusion chamber (figure 1 B and C), and for the introduction of the platinum microelectrode. The T-pieces (*b*) on the left side are used for the reference electrode. The lower part of the cylinder in figure 1 A is partly sand-filled and supplied with a water inlet.

After the cylinders are filled with the experimental soil, the diffusion chambers are inserted. The set-up is then placed in water, and the water table is kept constant by means of a Mariotti device at a level of about 40 cm below the soil surface. The soils are now left for obtaining saturation and equi-

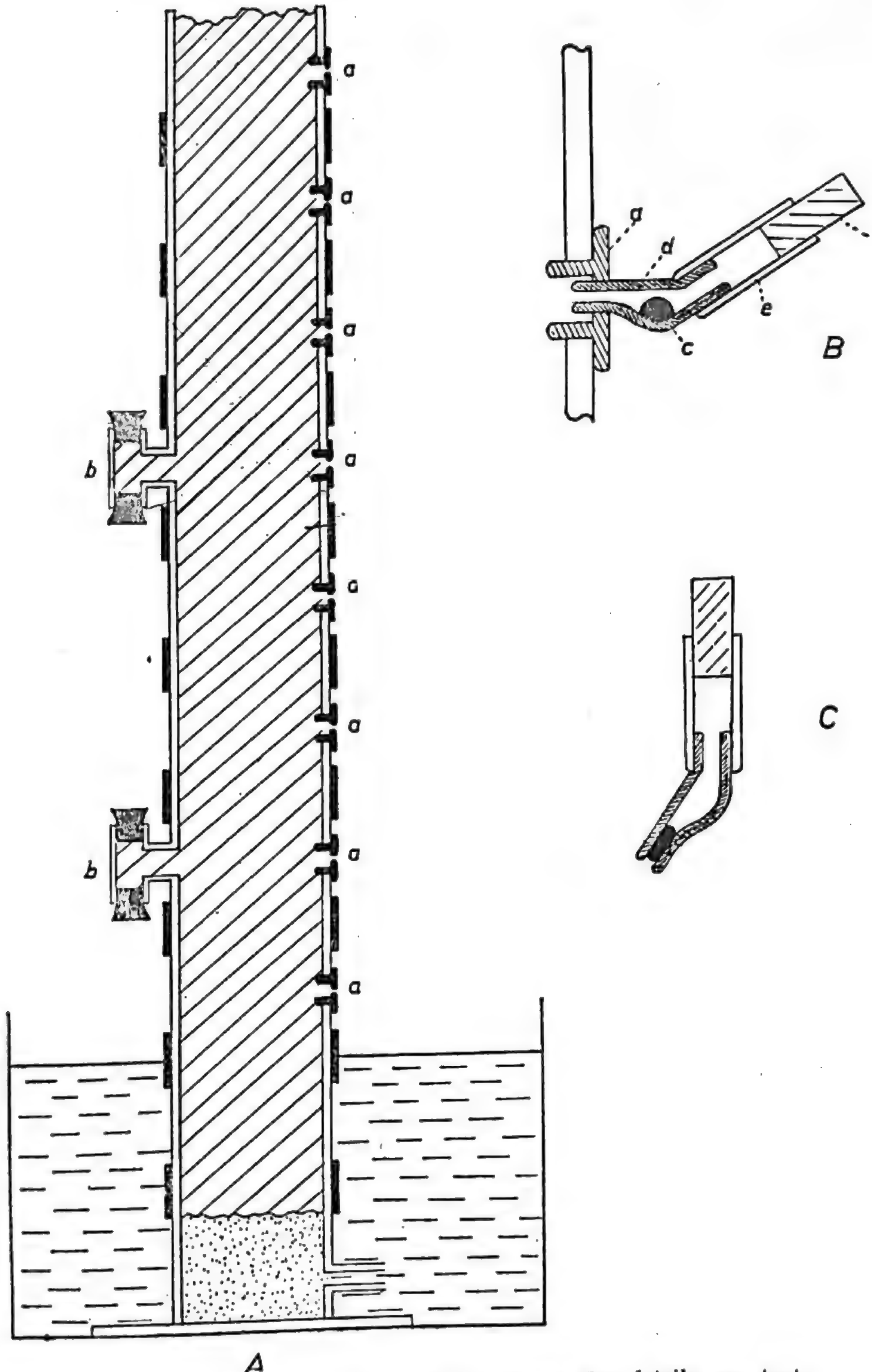

Fig. 1. Experimental set-up and diffusion chambers. For details see text.

librium. Measurements with micro-tensiometers (not shown in the figure) revealed that after capillary saturation, the suction was at all heights equal to the height above the ground water table when evaporation from the soil surface was low as in this experiment.

The diffusion chamber used is shown in mounted position in figure 1 B. A mercury droplet (*c*) is laying just inside the mouth of a fashioned glass tip (*d*), leaving a passage for gaseous diffusion between chamber and soil. The glass tip is provided with a short piece of clear plastic tubing (*e*), closed with a glass rod (*f*). The total volume of the chamber is about 0.2 cm^3.

Before removing the chamber it is tilted slightly upward. The mercury droplet then closes the inlet (fig. 1 C). When the mouth of the diffusion chamber has an inside diameter of 1—1.5 mm, it will be small enough to prevent the mercury droplet from running out. The air sample can now be transferred to the analysis apparatus without danger of mixing with "foreign" air. Analysis of the air sample is carried out immediately after removing the chamber from the soil column.

The soil air samples obtained are analyzed for oxygen and carbon dioxide content, using a modification of the Krogh (1908) apparatus for analysis of micro air-samples. This apparatus is shown schematically in figure 2. In the lower part the modification is shown, a device used for introducing the micro-sample of air to be analyzed without bringing it into contact with water and air.

When introducing the sample, the plastic tubing of the diffusion chamber is pressed gently so that the mercury droplet will extrude. The tip of the cham-

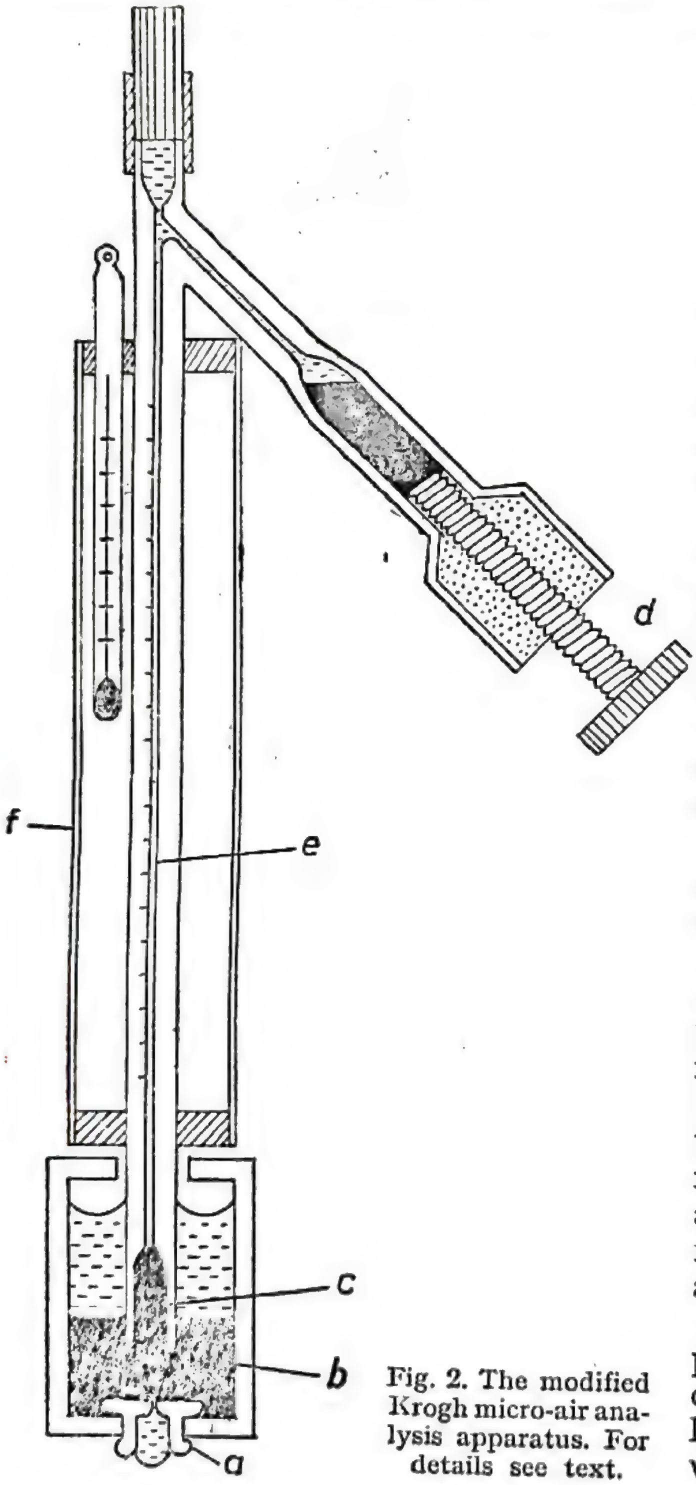

Fig. 2. The modified Krogh micro-air analysis apparatus. For details see text.

ber is then passed through a hanging water drop and is pressed through a punctation in the rubber stopper (*a*) into the mercury above (*b*). A small amount of the sample is pressed out of the chamber, and moves upward to the reaction chamber (*c*). By means of a micrometer screw (*d*) an adequate amount (about 0.005 cm^3 for the apparatus in question) of the sample is taken into the graduated capillary tube (*e*). The device used for the introduction of the air sample is then removed, leaving the reaction chamber water-filled. Surplus of air in the reaction chamber is removed by turning the apparatus upside down. The lenght of the sample in the capillary tube is measured. Then the water in the reaction chamber is replaced by a carbon dioxide absorber (30 per cent KOH), and by means of the micrometer screw the sample is returned to the reaction chamber. When freed from carbon dioxide the sample is measured again, and then returned for oxygen absorption into a solution containing 45 per cent KOH and 7 per cent pyrogallol. After a final measurement of the sample, its composition can be calculated on a volume basis.

The temperature will have some effect on the analysis. In order to minimize this effect the capillary tube is surrounded by a glass tube (f) containing water. The results can be corrected for temperature variation during analysis, but this is generally not necessary, as the time required is of a few minutes only for a skilled person.

Oxygen diffusion rate in the liquid phase of the soil was measured according to the principles given by Lemon and Erickson (1952, 1955). The platinum electrode used has a diameter of 0.5 mm and a lenght of 4.5 mm. The electrode is inserted through the ports immediately after the diffusion chamber is removed. The silver-silver chloride reference cell was placed in the side branch (figure 1 b) nearest to the measuring height. The soil in this side branch is moistured with potassium chloride, before measurement, and when the reference cell is removed again the soil is renewed in order to prevent diffusion of salt into the experimental soil.

RESULTS

The soil columns were kept at room temperature (23° ± 1°C) for a week with the ground water table kept constant before the air compositon in the diffusion chambers was determined. At the same time the oxygen diffusion rate was measured. The oxygen diffusion rate will be shortened below to *ODR* and the numbers given will have the unit: $gm \times 10^{-8} cm^{-2} min^{-1}$.

The results of the measurements in the three soils are given in figure 3. On the left side of this figure it is shown, that the soil air composition changes considerably as the ground water table is approached. For all the soils the oxygen content decreases to about zero and the carbon dioxide content increases to about 20 per cent before the water table is reached. The sum of the two gasses amounts to about 21 per cent at all depths down to about 10 cm from the ground water.

For the heaviest of the soils (III) there is a considerable drop in oxygen content already at a distance of 25—30 cm from the water table. In the soil with the lowest clay content (1) the oxygen content is not reduced appreciab-

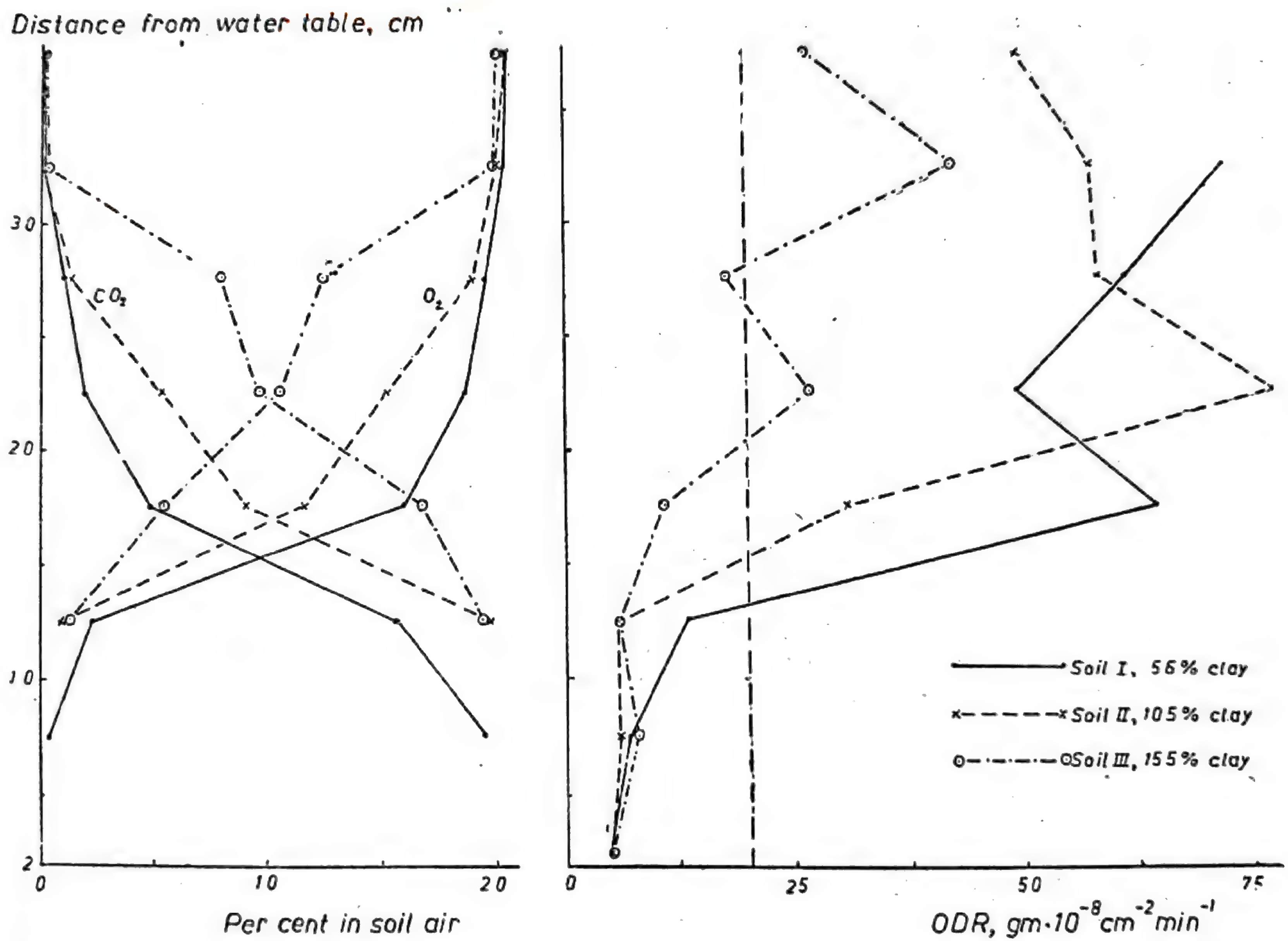

Fig. 3. Soil air composition and oxygen diffusion rate at different heights above a permanent ground water table.

ly before a distance of about 15 cm from the water table. Soil II is between the two other soils. It was not possible in this experimental series to obtain relibale samples down to the ground water table. The main trouble was caused by the formation of water drops in the inlet of the diffusion chamber, thus clogging the diffusion path.

The *ODR* for the three soils are shown in the right side of figure 3. Several measurements were taken at each level. A rather great variation within replicates was found. This variation is naturally largest for the highest *ODR*-values. For the low values found close to the water table good agreement was ascertained. The variation may partly be explained by the typical „grain structure" of the experimental soil. As the single structure units may be up to 2 mm in diameter, compared to the electrode diameter of 0.5 mm, there will be rather good possibilities for a different geometry around the electrode from one measurement to another. Each single structural element will have an independent aeration as discussed by Currie (1961). The *ODR* therefore will depend to some extent on whether the electrode passes through or between the structural elements.

The *ODR*-values shown in figure 3 are not corrected for residual current. Referring to the figure, this current apparently amounts to a value equal to about 5 *ODR*-units. This is of the same order of magnitude as found by Cowey and Lemon (1962).

The *ODR* decreases as the oxygen content in the soil air decreases, and also as the diffussion pathway in the liquid phase increases (i.e. as the water content increases). The relationship between these factors has been given by Lemon (1962) and can be written:

$$ODR = \frac{2\pi D_e L (C_R - C_p)}{\ln R - \ln r_e}$$

where D_e is the effective diffusion coefficient for oxygen in the matrix surrounding the oxygen absorber (electrode or plant root), L is the length of the absorber, C_R and C_p the oxygen activity at the surface of the absorber and at the air-liquid interface respectively, and $r_e - R$ represents the diffusion pathway. According to this equation *ODR* is directly proportional to the oxygen concentration in the soil air and inversely related to the diffusion pathway and thereby to the water content. The latter relationship was also demonstrated by Lemon and Kristensen (1960).

Figure 4 shows *ODR* versus the ratio: oxygen percentage in soil air/water content by volume. A reasonable good straight-lined relationship seems to exist for the lower *ODR-values*. The spreading of the points for higher values may partly be due to the conditions mentioned above.

Figure 5 shows the *ODR* plotted against the oxygen content in soil air for all the soils. As shown the *ODR* will generally be below 20 when the oxygen content comes to 14 per cent or below. Assuming *ODR* values of 20 to be critical to root growth (Bertrand and Kohnke, 1957; Lemon and Erickson, 1952; Letey et al., 1961, 1962; Stolzy et al., 1961; Wiersma and Mortland, 1953) it is seen, that in many cases soils having as much as 14 per cent oxygen in the air will not be able to support root growth although most plant species will thrive well in water cultures having considerably lower oxygen content.

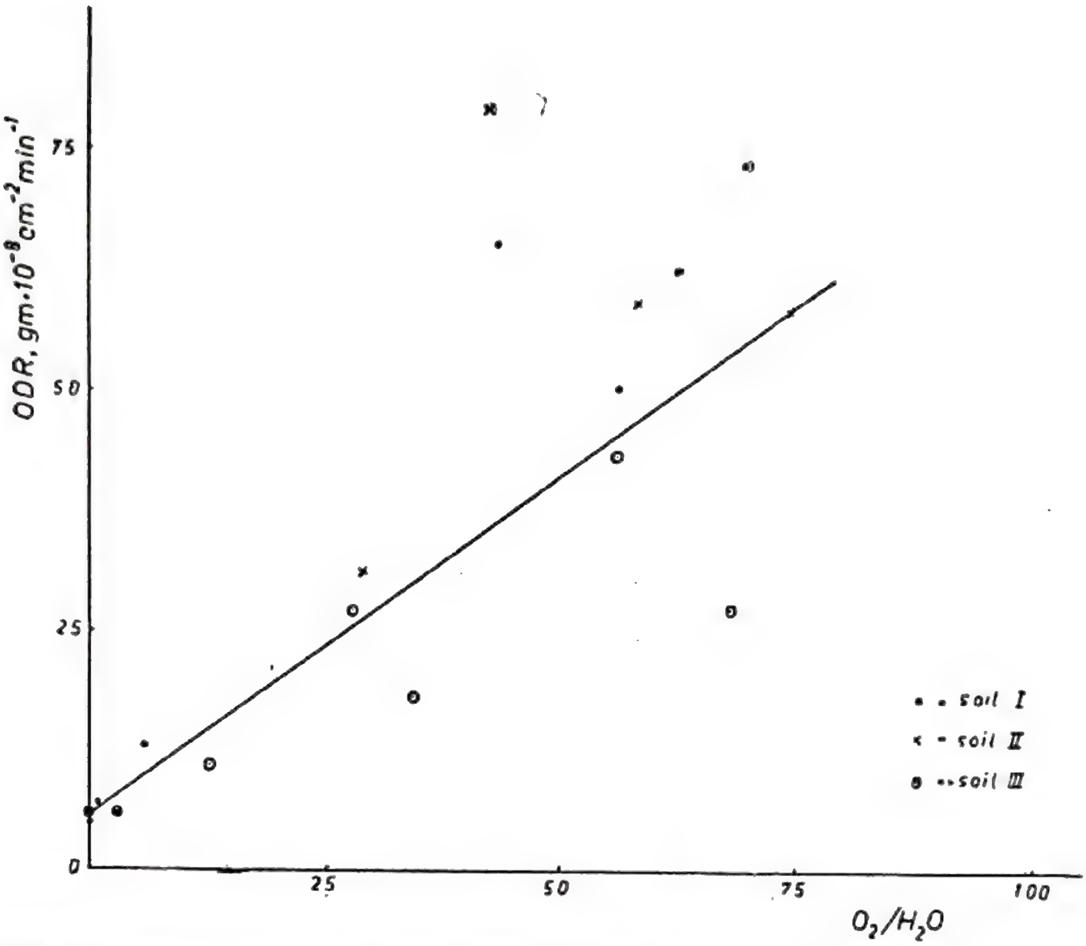

Fig. 4. Oxygen diffusion rate versus oxygen in the soil air (vol. per cent) over water content in the soil (vol. per cent).

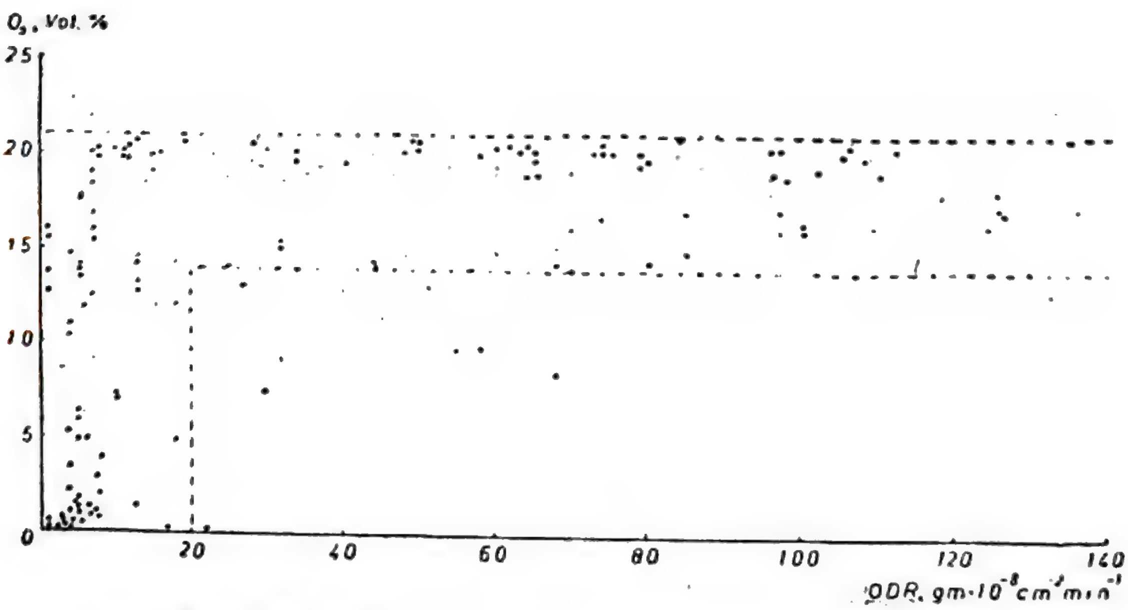

Fig. 5. Oxygen diffusion rate versus oxygen content in the soil air.

DISCUSSION

The results presented show a drastic decrease in the oxygen content of the soil air as the ground water table is approached. Simultaneously the carbon dioxide content increases at the same rate. It is not fully agreed upon whether it is lack of oxygen or surplus of carbon dioxide that makes such a medium unsuitable for the root of the most cultivated plants. Part of the literature (Michael and Bergman, 1954; Rajappan and Boynton, 1960; Stolwijk and Thimann, 1957) reports results indicating that carbon dioxide causes the main damage. Harris and van Bavel (1957) found growth limitations of tobacco when the ratio CO_2/O_2 exceeded unity, but it is generally found, that the carbon dioxide concentration may be very high (25—40 per cent) before damage occurs. Most of the literature (e.g. Childs, 1941; Gingrich and Russell, 1956; Harris and van Bavel, 1957; Leonard and Pinckard, 1946) shows that it is mainly oxygen deficiency that limits plant growth under conditions of poor aeration. The actual concentration of oxygen at which damage occurs seems to vary considerably. It reasonably depends on the plant species, stage of development, soil temperature and soil properties.

A reason for the varying and even contradicting results given in literature is, that it is not the oxygen concentration of the soil air *per se*, but rather the concentration at root surface that determines the oxygen status from the point of view of the plants. For a given respiration intensity the oxygen supply to the roots thus will depend both on the oxygen concentration in the soil air and on the resistance to diffusion in the liquid surrounding the root. The *ODR* which takes into consideration both these factors should be a useful parameter for characterizing soil aeration.

Several investigators have in recent years found a characteristic relationship between root growth and *ODR*. Lemon and Erickson (1952) found *ODR*-values of 20—40 to be critical for the growth of tomato roots. Wiersma and Mortland (1953) and Bertrand and Kohnke (1957) found values of 20—30 to be critical for the roots of sugar beets and corn. Letey et al. (1961, 1962) and Stolzy et al. (1961) found values of 15—25 to be critical for root growth in sunflower, cotton, barley, and snapdragons. Proportionality between *ODR* and growth intensity is reported for different plant species up to *ODR*-values of 50—70 (Cline and Erickson, 1959; Doyle and McLean, 1958; Erickson and van Doren, 1960). The demand seems to vary with plant species and stage of development. Especially the germination seems to demand high *ODR*-values. Hanks and Torph (1956) and Jackson (1962) found that satisfactory germination of wheat and potato sprouting required *ODR*-values of 60 to 80.

In figure 3 there is a broken line at $ODR = 20$. In accordance with the major part of the cited literature it is assumed that root growth practically stops at lower values. Assuming this to be correct it is seen, that root growth will stop at a distance of about 30 cm from the ground water table in soil III, while it will continue to about 15 cm from the water table in the two other soils. Assuming root growth to depend on *ODR* up to 50, there will not be possibilities for satisfactory root development in the heaviest of the soils (III). It seems reasonable to assume, that on the heavier soils a satisfactory root

development cannot take place in the vicinity of the water table. The lack of root volume under conditions with a stagnant ground water table may on such soils complicate the water supply during periods with high evaporating demand.

As these few and preliminary investigations are carried out under laboratory conditions and with disturbed soils, the results may not be directly applicable to field conditions. It might be reasonable, however to presume that where shallow, stagnating ground water tables occur in the field, conditions may be even worse than those here demonstrated.

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SUMMARY

A short description is given of a laboratory set-up for the study of the change in soil air composition and the oxygen diffusion rate as a stagnating ground water table is approached. Also a cheap and convenient apparatus for analysis of micro air-samples is described. Results for three different soils varying in their clay content (5.6, 10.5, and 15.5 per cent) show, that the oxygen content decreases to zero and the carbon dioxide content increases to about 20 per cent before the ground water table is reached. The sum of the two gases is about 21 at all depths. The change in soil air composition occurs in the expected succession for the three soils. The heaviest of them shows a drastical change at a greater distance from the water table than the lighter one. Also the oxygen diffusion rate decreases rapidly with increasing soil depth, and it comes virtually to zero before the ground water table is reached.

RÉSUMÉ

On donne une courte description d'une installation de laboratoire pour l'étude des changements dans la composition de l'air du sol et de la vitesse, de diffusion de l'oxygène lorsqu'une nappe phréatique stagnante est approchée. On donne même la description d'un appareil bon marché et convenable pour l'analyse des microéchantillons d'air. Les résultats pour trois sols distincts, à teneur différente en argile (5,6 , 10,5 et 15,5%) montrent que la teneur en oxygène descend à zéro et la teneur en bioxyde de carbon monte à environ 20% avant que le plan de la nappe phréatique soit atteint. La somme des deux gaz est d'environ 21 à toutes les profondeurs. Le changement dans la composition de l'air du sol se produit pour les trois sols dans la succession attendue. Le sol à texture fine présente un changement drastique à une plus grande distance de la nappe phréatique que celui qui est plus sablonneux. De même la vitesse de diffusion de l'oxygène décroît rapidement avec l'accroissement de la profondeur du sol et elle arrive virtuellement à zéro avant que le plan de la nappe phréatique soit atteint.

ZUSAMMENFASSUNG

Es wird eine kurze Beschreibung einer Laboratoriumseinrichtung für das Studium der Veränderung der Bodenluftzusammensetzung und des Sauerstoffdiffusionsgrades, wenn ein stagnierender Grundwasserspiegel angenähert wird, gegeben. Ebenfalls wird ein billiges und dienstliches Gerät für Luftmikroproben-Analyse beschrieben. Die Ergebnisse für drei nach ihrem Tongehalt verschiedene Böden (5,6, 10,5 und 15,5%) zeigen, dass der Sauerstoffgehalt zu Null sinkt und dass der Kohlendioxydgehalt zu rund 20% ansteigt bevor der Grundwasserspiegel erreicht ist. Die Summe der zwei Gase ist ungefähr 21 in allen Tiefen. Die Veränderung in der Bodenluftkom-

position für die drei Böden geschieht in der erwarteten Reihenfolge. Der schwerste unter ihnen zeigt eine drastische Veränderung bei einer grösseren Entfernung vom Wasserspiegel als der leichtere.Der Sauerstoffdiffusionsgrad sinkt ebenfalls schnell mit zunehmender Bodentiefe und gelangt so gut wie zu Null, bevor der Grundwasserspiegel erreicht ist.

DISCUSSION

P. BRUIN (Netherlands). Did you determine the pore space distribution?

K. J. KRISTENSEN. No, we did not.

D. KIRKHAM (U.S.A.). Were different levels of organic matter considered in your experiments?

K. J. KRISTENSEN. No, the organic content was the same for all the soils. The soils differ only in their clay and silt content.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

NEW TECHNIQUES FOR RELATING SOIL AERATION AND PLANT RESPONSE[1]

A. E. ERICKSON, J. M. FULTON, G. H. BRANDT[2]

Relating soil structure to the growth of plants is a complex difficult problem. The fact that the system is also dynamic adds to the difficulty.

Often studies of soil structure not only neglect the dynamic character of the system but attempt to describe a certain isolated property of the structure and relate this to plant response without considering the various other factors which influence the system. Consideration of the changes that occur in a seed bed after plowing illustrates the complexity of the problem.

After plowing, the seed bed consists of an assortment of aggregates more or less loosely packed. With time, tillage, rainfall, traffic and weathering cause the aggregates to rearrange, settle and coalesce into a matrix or fabric. This matrix, which is usually measured by pore size distribution analysis, is the skeleton on which the soil water is supported and both the matrix and the water determine the aeration properties. Although excess water may limit the exchange of air in the soil, the amount of water in the soil is extremely variable. The quantity of water in the soil depends not only on the matrix but also on the supply from rainfall or irrigation and removal by drainage and evapotranspiration. However, the final yield of a crop will depend on the ability of the soil to supply water and air to plant roots throughout the season. To attempt to relate aggregate analyses to plant response is to assume that all other factors such as weather are constant and will be the same next season. To relate the adequacy of water and oxygen to the plants throughout the growing season seems to be the first step and the shorter step to understand the influence of soil structure on plant growth. In the humid region or under good irrigation where water is not limiting, the problem can be simplified to the study of oxygen availability. This has been the rationale for our studies of oxygen diffusion rates as they relate to plant growth and yield in the humid region.

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[2] Professor, and former research assistants in Soil Science, respectively (now Research Branch, Canada Dept. of Agriculture, Harrow, Ontario, and Dow Chemical Co., Midland, Michigan, U.S.A.).

Using the platinum microelectrode technique of Lemon and Erickson (1952, 1955), Erickson and van Doren (1960) and others have demonstrated the relevance of these measurements of soil oxygen availability to plant growth and yield. Limits of oxygen availability for optimum plant growth have been defined and some data on the short term effects of plant suffocation have been reported.

Our recent studies have had two objectives: 1) to determine if there is some biochemical reaction of the plant that could be used to indicate suffocation or partial suffocation, and 2) to devise a method to determine the concentration of oxygen within the soil moisture films in the root environment. If the first objective could be achieved, a plant tissue test for soil oxygen deficiency might be possible. This would simplify studies on the adequacy of soil aeration for a particular crop at a particular time. If the second objective were achieved, it would be possible to measure biologic demand for oxygen throughout the soil fabric and correct the oxygen diffusion rates for these differences in oxygen concentration. The diffusion measurement would then be a characteristic of soil fabric *per se*.

PLANT TISSUE TEST FOR SOIL OXYGEN STRESS

Our studies of biochemical reactions of plants have been concerned with concentration of ethyl alcohol (Kenefick, 1962; Fulton and James 1963). It was reasoned that under soil oxygen stress alcoholic fermentation reactions may proceed in the plants with an accumulation of ethyl alcohol. Tomatoes which were grown in the greenhouse were used as an indicator plant. A gas cromatograph with hydrogen flame detector was used to measure the small concentrations of ethyl alcohol in the xylem exudates of the tomatoes. Plants were grown normally until the time of treatment. The oxygen stress treatments were applied by raising the water table in the soil. Then the top of the plant was cut off with a sharp knife. A small length of rubber tubing was placed on the end of the cut stem to form a cup to collect the xylem exudate which was then transferred to the chromatograph for the determination of ethyl alcohol. It was found that ethyl alcohol concentrations reached a maximum twelve hours after the beginning of soil oxygen stress, that tomatoes accumulate more ethyl alcohol in the light than in the dark, and that plants that had just started to blossom accumulate more ethyl alcohol than younger plants.

Figure 1 shows the relationship between ethyl alcohol concentration of the xylem exudate of tomato plants and the average oxygen diffusion rates in the root zone. The tomatoes bearing three open flowers were under oxygen stress for twelve hours in the light. This curve is very similar to the growth and yield curves obtained in other experiments. Ethyl alcohol appears when the oxygen diffusion rate drops below a value of $38 \cdot 10^{-8} g \cdot cm^{-2} \cdot min^{-1}$ which is the same critical region in which the growth and yield of plants respond. Other studies (Fulton, 1963) demonstrate the toxicity of these concentrations of ethyl alcohol to plant growth.

Table 1 lists the ethyl alcohol concentration of the xylem exudates of several different plants that were grown in the greenhouse, flooded for twelve hours in the light, and the ethyl alcohol concentration of the xylem exudate determined. All plants were flowering except the tobacco that was 15 cm high and

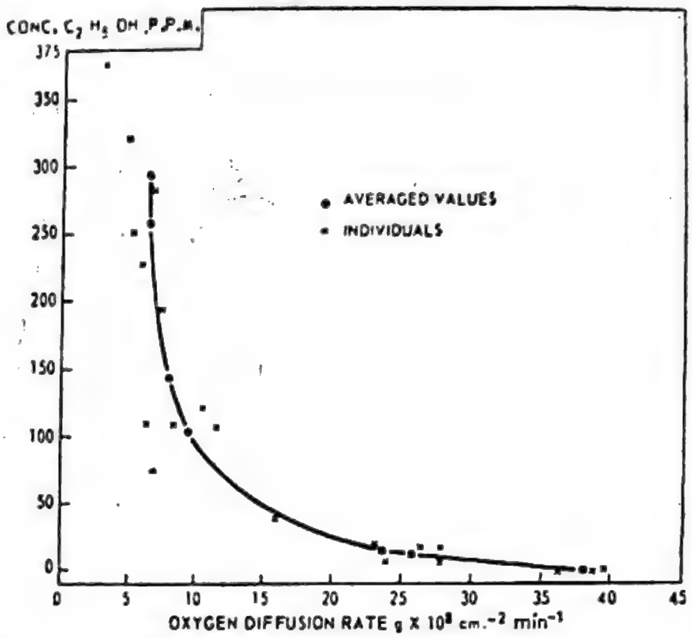

Fig. 1. Relationship of soil aeration to ethyl alcohol concentrations of tomatoes xylem exudates twelve hours after initiation of oxygene stress.

the sugar beets that were 10—15 cm. All of the oxygen stressed plants produced xylem exudates which had more ethyl alcohol than did the normal plants. With the exception of plants which required expression of the plant sap, the ethyl alcohol concentration of the normal plants was very low. It appears that these plants produce and accumulate ethyl alcohol when under soil oxygen stress and that principle has rather wide application to crop plants.

Pieces of stem tissue were taken when the plants were decapitated and placed in a vessel, quickly frozen and stored for two months. These were later

Table 1

Ethyl alcohol concentration of xylem exudates of control plants and plants flooded twelve hours in the light

Plant	Ethyl alcohol concentration ppm	
	Control	After 12 hours flooding
Cucumber	0	250
Potato	3	72
Pea beans	16	160
Peas	38	164
Tomato	0	291
Tobacco	190*	340
Sugar beet	190*	730

* No exudate — tissue squeezed to express fluid.

thawed, the fluids expressed and ethyl alcohol determined. Although the exudates and the expressed plant fluid from tissue frozen and stored for two months did not agree precisely, the values were of the same order of magnitude. These techniques still need field testing but they show promise of producing a tissue test for soil oxygen deficiency.

OXYGEN CONCENTRATION WITHIN SOIL WATER FILMS

An oscilloscopic polarographic microelectrode technique using a bare silver wire has been developed to measure oxygen concentration within the soil water-films (Brandt and Gerald, 1963). The principle is the same as that for measuring oxygen diffusion rates with the platinum microelectrode, (Lemon and Erickson, 1955), except that only the very early (first second) portion of the time-current curve is used. In this portion of the curve oxygen diffusion to the electrodes can be considered to be linear to the cylindrical wire surface and the current proportional to the concentration of oxygen. A silver wire electrode is used instead of platinum because the surface is less reactive than the platinum surface and gives better reproducibility.

The procedure involves placing a —0.65 volt, 2 second square wave pulse to a 0.625 mm diameter silver wire which has been tygon coated except for the 4 mm tip. The circuit is completed through a silversilver chloride cell with a saturated potassium chloride bridge. Current versus time curves are measured with an oscilloscope and recorded by a poloroid camera. The area under the curve between 0.1 and 0.4 s is measured as it is in this range of time that these electrodes give a constant and theoretical $i\sqrt{t}$. The electrodes are calibrated in three per cent bentonite suspensions in 0.01 N Na_2SO_4 that are at equilibrium with various partial pressures of oxygen. This gives a straight line relation between oxygen concentration and the area under the curve. Calibrations are repeated frequently and if the calibration of an electrode changes appreciably, it is discarded.

To illustrate the capability of these electrodes, an air dry 7.5 $\times$ 7.5 cm soil clod was placed in a vessel which was three times evacuated and 10 per cent oxygen, 90 per cent nitrogen gas mixture introduced. The clod was then wetted with water that was in equilibrium with 10 per cent oxygen, 90 per cent nitrogen mixture to about 10 cm moisture suction. The silver electrodes recorded an average of 11.5 $\pm$ 0.3 per cent oxygen. An air saturated clod wetted with air saturated water was measured at 21 per cent oxygen. The air saturated clod was then allowed to stand for three days at 70°F. Electrodes 1 mm below the surface measured 14 per cent oxygen, whereas at approximately 3 mm depth they ranged from 7.5 to 10.2 per cent oxygen and at 5 cm depth ranged 1.6—1.8 per cent oxygen. This shows the marked variability of oxygen within the soil mass and bears out the findings of Brandt et al. (1964) who found wide differences in the activity of the microflora and in oxygen diffusion rates at the surface and within aggregates.

This method shows promise of providing oxygen concentration data which can be used to correct the oxygen diffusion measurements so that the oxygen diffusion rates will reflect the structure of the soil *per se* without the confounding influence of biological oxygen sinks.

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SUMMARY

A modified microelectrode technique is used to measure oxygen concentration in the soil solution within the root environment. This method allows the evaluation of oxygen consumption in the soil and makes possible the determination of oxygen diffusion rates that are due to the soil structure *per se.*

Studies of tomato xylem exudate show a close correlation between ethyl alcohol concentration and oxygen diffusion rate in the soil. Ethyl alcohol in plant sap is therefore proposed as tissue test for soil oxygen deficiency.

RÉSUMÉ

On utilise une technique modifiée de la micro-électrode pour mesurer la concentration de l'oxygène dans la solution de sol au voisinage de la racine. Cette méthode permet d'évaluer la consommation d'oxygène dans le sol et rend possible de déterminer les vitesses de diffusion de l'oxygène qui sont dues à la structure du sol par elle-même. Des études sur les exsudats du xylem des tomates montrent une corrélation serrée entre la concentration en alcool éthylique et la vitesse de diffusion de l'oxygène dans le sol. C'est pourquoi on propose la présence de l'alcool éthylique dans la sève des plantes comme test de tissu pour le déficit en oxygène du sol.

ZUSAMMENFASSUNG

Es wird eine abgeänderte Mikroelektrodentechnik angewandt, um die Sauerstoffkonzentration der Bodenlösung innerhalb der Wurzelumgebung zu messen. Diese Methode gestattet den Sauerstoffverbrauch im Boden abzuschätzen und ermöglicht die Geschwindigkeit der Sauerstoffdiffusion zu bestimmen, welche der Bodenstruktur an sich zu verdanken ist.

Studien über die Xylemexsudate von Tomaten zeigen eine enge Korrelation zwischen Äthylalkoholkonzentration und Sauerstoffdiffusionsgeschwindigkeit im Boden. Das Vorkommen von Äthylalkohol im Pflanzensaft ist deswegen als eine Gewebeprobe für den Sauerstoffmangel des Bodens vorgeschlagen.

DISCUSSION

P. BRUIN (Netherlands). Did you find any relation between the air content at various pF-values and the diffusion rate of O_2?

A. E. ERICKSON. We have not studied this as yet but I am sure we will find a relation.

TEMPERATURHAUSHALT EINIGER BODENTYPEN DER UdSSR

W. N. DIMO [1]

Unter dem Wärmehaushalt des Bodens verstehen wir die Gesamtheit verschiedener Wärmeumtauscherscheinungen im System: bodennahe Luftschicht — Boden, — Gestein, sowie die Prozesse der Wärmeübertragung und Wärmeakkumulation im Boden selbst, die voneinander stets abhängig sind.

Die Temperatur des Bodens charakterisiert seinen Wärmezustand und ist ein Hauptmerkmal seiner Wärmeverhältnisse. Es wurde bereits von Woyeikow (1903) gezeigt, dass die Jahrestemperatur des Bodens immer höher als die der Lufttemperatur ist. Die Unterschiede zwischen diesen Temperaturen vermindern sich (Khrigian, 1937) in der Richtung vom Norden zum Süden von 3,0 bis 0,6°C und im Osten erreichen sie 4,9°C. Gleichartige Daten hat Archipowa (1954) erhalten. Die weiteren Arbeiten vieler Forscher betreffen den Temperaturhaushalt des Bodens nur bis zur Tiefe von 0,2 m und geben eine geringe Möglichkeit, über die Versorgung der Pflanzen mit Bodenwärme zu urteilen. Ausserdem können sie nicht die Gesetzmässigkeit des Wärmeumtausches im Boden selbst aufklären, der durch den Charakter und die Richtung der gegenwärtigen Bodenbildung beeinflusst wird.

Hier werden die Ergebnisse vieljähriger Beobachtungen, die in Nachschlagebüchern für Klimatologie veröffentlicht sind, sowie die Angaben vieler Forscher (darunter auch unsere) betreffend den Europäischen Teil der UdSSR zwischen 30 und 40° Meridianen angeführt.

Den Temperaturhaushalt der lehmigen Böden betrachten wir auf Grund des Beispiels der folgenden boden-bioklimatischen Gebiete der Zonen und Subzonen [2]:

V *Zentrales Taiga-Waldgebiet*
V_1 — Nördliche Taigasubzone gley-podsoliger Böden,
V_2 — Zentrale Taigasubzone gley-podsoliger Böden,
V_3 — Südliche Taigasubzone rasen-podsoliger Böden,

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[1] Dokutschaew-Bodenkundliches Institut, Moskau, UdSSR.
[2] Im weiteren werden von uns nur Indexe entsprechend der Boden karte im Masstab 1:12500000 und der boden-geographischen Rayonierung der UdSSR (1960) benützt.

V_4 — Laub-Waldzone grauer Waldböden.
J *Zentrales Wald-Steppen-und Steppengebiet*
J_1 — Wald-Steppenzone podsolierter, ausgelaugter und typischer Tschernoseme,
J_2 — Steppenzone gewöhnlicher südlicher Tschernoseme,
J_3 — Dürrsteppenzone der dunkelkastanien- und kastanienfarbigen Böden.

Der Temperaturhaushalt des Bodens ist durch folgende Merkmale charakterisiert:

a) Jahrestemperaturen der Luft und des Bodens (in der Tiefe 0,2 und 1,6 m), ihre Amplituden und Unterschiede;

b) Durchdringungstiefe der Temperaturen $< 0°C$ und $> 10°C$.

Die Bodentemperatur in der Tiefe 0,2 m ist das Merkmal des durchschnittlichen Wärmezustandes in der Wurzelschicht.

Die Bodentemperatur in der Tiefe 1,6 m charakterisiert den Wärmezustand des Bodens ausserhalb der Grenzen des Eindringens des Wurzelsystems der Hauptkulturpflanzen. Die biologisch aktive Bodenwärmung entspricht der Tiefe des Durchdringens von Temperaturen höher als 10°C.

Das Erkalten wird mit der Durchdringungstiefe negativer Temperaturen charakterisiert. Die Temperaturamplitüden bestimmen den Grad des Ausdrucks des kontinentalen Bodenklimas.

Um den Temperaturhaushalt der Böden mit den klimatischen Merkmalen zu vergleichen, führen wir in der Tabelle 1 für die obgenannten Bodenzonen und Subzonen die jährlichen Grössen der Sonnenradiation und Radiationbilanz an, die aus dem Atlas der Wärmebilanz der UdSSR (1955) entlehnt werden.

Die Summe aktiver Lufttemperatur ($> 10°C$) wird nach den Angaben des klimatischen Atlasses der UdSSR (1960) angeführt. Die Niederschlagsmenge, die maximale Höhe der Schneedecke und die Dauer der Perioden positiver Luft- und Bodentemperaturen (0,2 m) werden nach klimatologischen Nachschlagebüchern angegeben.

Die Grössen dieser Merkmale für verschiedene Bodenzonen und Subzonen sind in der Tabelle in der Meridianrichtung vom Norden nach Süden angeordnet und stellen die Mittelangaben für 1—3 Stellen jeder Zone oder Subzone dar.

Die summarische Sonnenradiation (S) und die Radiationsbilanz (R) sind für Subzonen V_3, V_4 und J_1 gleich und schwanken entsprechend innerhalb 80—100 und 20—40 kcal/cm² pro Jahr. Die Zonen J_2 und J_3 werden mit Grössen $S = 100 — 120$ und $R = 40 — 60$ kcal/cm² pro Jahr charakterisiert. In der Subzone V_1 sind S und R kleiner als 80 kcal/cm² pro Jahr. In der Subzone V_2 ist S kleiner als 80 und R beträgt 20—40 kcal/cm² pro Jahr. Die Summen aktiver Temperaturen und vieljährige Mitteltemperaturen der Luft vergrössern sich in der Richtung vom Norden nach Süden von 1 200 bis 3 400 und von 0,4 bis 10°C. Die maximale Höhe der Schneedecke nimmt von Subzone B_1 (60—70 cm) zur Zone J_3 (kleiner als 10 cm) ab. Die Niederschläge vermindern sich auch vom Norden nach Süden. Die Periode aktiver

Lufttemperaturen dauert 6 Monate in Subzone V_1; in Subzone J_3 aber erreicht sie 10 Monate.

Das sind die gemeinsamen klimatischen Merkmale des betrachteten Gebiets. Die vieljährigen Mitteltemperaturen des Bodens in der Tiefe 0,2 m und 1,6 m sind fast gleich. Es sei jedoch beachtet, dass im nördlichen Teil (Subzonen V_1, V_2 und V_3) die Bodentemperaturen in der Tiefe 0,2 m niedriger als in der Tiefe 1,6 m sind. Also dominiert in der Wurzelschicht während des vieljährigen Wärmeumtausches der Erkaltungsprozess. Man kann also, hier über den heraufgerichteten positiven Temperaturgradienten sprechen. Im südlichen Teil (Zonen V_4, J_1, J_2, J_3) dominiert in der Wurzelschicht während des vieljährigen Wärmeumlaufs der Erwärmungsprozess und der hinuntergerichtete konventionelle negative Gradient der Jahrestemperaturen. Woyeikow (1903) hatte als erster die Aufmerksamkeit auf den Unterschied zwischen Luft- und Bodentemperaturen in verschiedenen Tiefen gelenkt und die Zergliederung der vertikalen Einteilung der Jahrestemperatur in Sonnentyp und Radiationstyp (wenn Schneedecke vorhanden ist — Schneetyp) vorgeschlagen.

Die Mangelhaftigkeit der Angaben gestattet uns nicht diese vorläufige Einteilung zu begründen und zu entwickeln.

Es ist ganz klar, dass im vierundzwanzigstündigen und den Saisonzyklen sich die Richtung und der Gradient der Bodentemperatur vollkommen verändern. Was die Jahresgradiente der Temperatur betrifft, bezeichnen sie nur die Dauerhaftigkeit des positiven Temperaturgradienten im Boden. In Abbildung 1 werden die Unterschiede der Bodentemperaturen in den Tiefen 0,2 m und 1,6 m für äussere nördliche Subzone V_1 und für äussere südliche Subzone J_3 gezeigt. Die Ordinatenachse bezeichnet die Veränderungen der Bodentemperaturen zwischen den genannten Tiefen und die Abszissenachse —die Monate.

Die Nullinie entspricht dem Gleichgewichtszustand der Bodentemperatur. Oberhalb von dieser Linie werden die Temperaturveränderungen beim positiven heruntergerichteten Gradient bezeichnet (der Boden ist kühler in der Tiefe 0,2 m als in der Tiefe 1,6 m) und unterhalb von ihr — beim negativen hinuntergerichteten Gradient (der Boden ist wärmer in der Tiefe 0,2 m als in der Tiefe 1,6 m). Der Zeiger bezeichnet die Richtung des Temperaturgradienten im Boden. Im Norden charakterisieren positive Gradiente den Wärmezustand des Bodens im Laufe von 7 Monaten, und das bringt seine positiven mitteljährigen Werte hervor. Im Süden bewahrt sich der positive Gradient nur während 6 Monate.

Die Unterschiede der Bodentemperatur in Tiefen 0,2 m und 1,6 m sind gering, sie betragen nur Zehntel-Gradteile. Die Angaben der Nachschlagebücher für Klimatologie zeigen jedoch, dass im nördlichen Europäischen Teil der UdSSR und auch in Westsibirien die Bodentemperaturen in der Tiefe 0,2 m immer niedriger als in der Tiefe 1,6 m und 3,2 m sind. Dabei stellt es sich heraus, dass je nördlicher die Beobachtungsstelle, desto grösser der Temperaturunterschied ist. Im Zentralteil dominieren höhere Jahrestemperaturen in der oberen Schicht, aber es werden auch gleiche Temperaturen beobachtet, und manchmal sind sie niedriger als in den tieferen Schich-

ten. Im südlichen Teil sind obere Schichten in der Regel wärmer als die unteren. Die Richtung des Temperaturgradienten im Boden übt zweifellos einen grossen Einfluss auf die Bodenbildung aus. Die Jahresamplitude der Bodentemperatur ist auch von grosser Bedeutung. Sie bestimmt den Grad der Ausprägung des "kontinentalen" Bodenklimas und damit die Intensität der physikalischen und chemischen Verwitterung.

Aus der Tabelle 1 kann man ersehen, dass die Jahresamplituden der Bodentemperaturen in den betrachteten Tiefen 0,2 und 1,6 m in der Richtung vom Norden nach Süden von 16—18°C und 7—9°C entsprechend bis 23—25 und 13—15°C zunehmen. Die Amplitude der Lufttemperaturen bleibt aber praktisch stabil, und in der Zone J_3 nimmt sie ab (26°C). Das "kontinentale" Bodenklima nimmt in der Meridianrichtung vom Norden nach Süden zu, unabhängig vom Grad der Ausprägung des kontinentalen

Tabelle

Verteilung der klimatischen Merkmale und Elemente des Boden

Index der Zone und Subzone	Summarische Sonnerradiation kcal/cm² pro Jahr	Radiationsbilanz kcal/cm² pro Jahr	Summen aktiver Temperaturen °C	Jahrestemperaturen			Jahresamplituden		
				der. Luft	des Bodens in der Tiefe *		der Luft	des Bodens in der Tiefe	
					0,2 m	1,6 m		0,2 m	1,6 m
V_1	80	20	1200—1400	0—1	4—5	4—5	28—30	16—18	7—9
V_2	80	20—40	1400—1600	1—2	4—5	4—5	28—30	16—18	7—9
V_3	80—100	20—40	1600—2000	2—4	5—7	5—7	28—30	17—20	9—12
V_4	80—100	20—40	2000—2400	3—5	7—8	7—8	28—30	19—21	10—12
J_1	80—100	20—40	2400—2800	5—7	8—9	8—9	28—30	20—22	11—13
J_2	100—120	40—60	2800—3200	7—9	9—11	9—11	26—29	22—24	12—14
J_3	100—120	40—60	3200—3400	9—11	11—13	11—13	25—27	23—25	13—15

* Unterschiede in Jahrestemperaturen sind in diesen graphischen Darstellungen nicht gezeigt, weil Durchschnittsgrössen für eine Zone oder Subzone gegeben sind. In den nächsten graph. Darstellungen sind sie angeführt.

Klimas der bodennahen Luftschicht. Das ist mit der Verminderung der Schneedecke in derselben Richtung erklärt. Die Jahrestemperaturen des Bodens sind immer höher als die Temperaturen der Luft. Die angeführten Angaben zeigen, dass der Unterschied zwischen diesen Temperaturen im Norden mehr als 4°C und im Süden nur 2°C beträgt, was auch mit der Verminderung der Schneedecke verbunden ist. Zugleich schwankt die Durchdringungstiefe negativer Temperaturen in den Böden in geringem Massstab, und sie hängt nicht von der Breite des Gebietes ab. Im nördlichen Teil des betrachteten Gebietes ist der Einfluss niedriger Lufttemperaturen von der

grossen Schneedecke kompensiert. Im südlichen Teil nimmt ihr Einfluss mit der Verminderung der Schneedecke zu. Die Korrelationsabhängigkeit zwischen dem Unterschied der Luft- und Bodentemperaturen und der Höhe der Schneedecke wurde von Chrigian (1937) entdeckt. Ähnliche Angaben wurden auch von Archipowa (1954) vorgeführt. Das Zunehmen der Bodentemperaturen in der Richtung vom Norden nach Süden entspricht der Zunahme der Lufttemperatur, aber es geschieht nicht so heftig. Die Unterschiede der Lufttemperaturen in Subzone V_1 und Zone J_3 betragen 10°C und die der Bodentemperaturen —6°C. Also sind die Böden im nördlichen Teil des betrachteten Gebiets wärmer als die Böden im Süden.

Die angeführten Angaben ermöglichen uns jetzt den Temperaturhaushalt in verschiedenen boden-bioklimatischen Zonen und Subzonen des Europäischen Teils der UdSSR zwischen 30° und 40° Meridianen zu charakterisieren.

7

temperaturhaushaltes in Meridianrichtung vom Norden nach Süden

Unterschiede der Jahrestemperaturen		Durchdringungs — tiefen		Periode positiver Temperaturen		Nieder-schläge mm pro Jahr	Maximale Höhe der Schnee-decke
des Bodens in der Tiefe 0,2 m und der Luft	des Bodens in der Tiefe 0,2 m 1,6 m	< 0 °C	> 10°C	der Luft	des Bodens		
		in m		in Monaten			
4	—0,1 — —0,3	0,3—0,6	1—2	V-X	V-XI	500—550	0,6—0,7
3	—0,1 — —0,3	0,5—0,7	1—2	IV-XI	IV-XI	500—550	0,7—0,8
3	—0,1 — —0,3	0,2—0,8	2—3	IV-XI	IV-XII	500—550	0,4—0,6
2,5	0	0,2—0,4	3—3,5	IV-X	IV-XI	550—600	0,2—0,4
2	+0,1 — +0,3	0,3—0,5	3,5—4	IV-XI	IV-XI	500—550	0,2—0,3
2	+0,1 — +0,3	0,4—0,6	4—5	III-XI	III-XII	400—500	0 —0,2
2	+0,1 — + 0,3	0	5—6	III-XII	das ganze Jahr	350—400	0,03

In den Subzonen V_1 und V_2 betragen die Durchschnittstemperaturen des Bodens in der Tiefe 0,2 m 4—5°C, die Durchdringungstiefe aktiver Temperaturen erreicht 1,2 m; dabei sind die Jahresamplituden 16—18°C in der Tiefe 0,2 m und 8—10°C in der Tiefe 1,6 m.

In der Subzone V_3 sind diese Grössen 5—7°C, 2—3 m und die Jahresamplituden — 17—20°C und 9—12°C.

Obwohl die Zonen V_4 und J_1 zu ganz verschiedenen boden-bioklimatischen Gebieten gehören, unterscheiden sie sich sehr wenig in bezug auf den Temperaturhaushalt. Für sie sind charakteristisch Bodentemperatur 7—9°C,

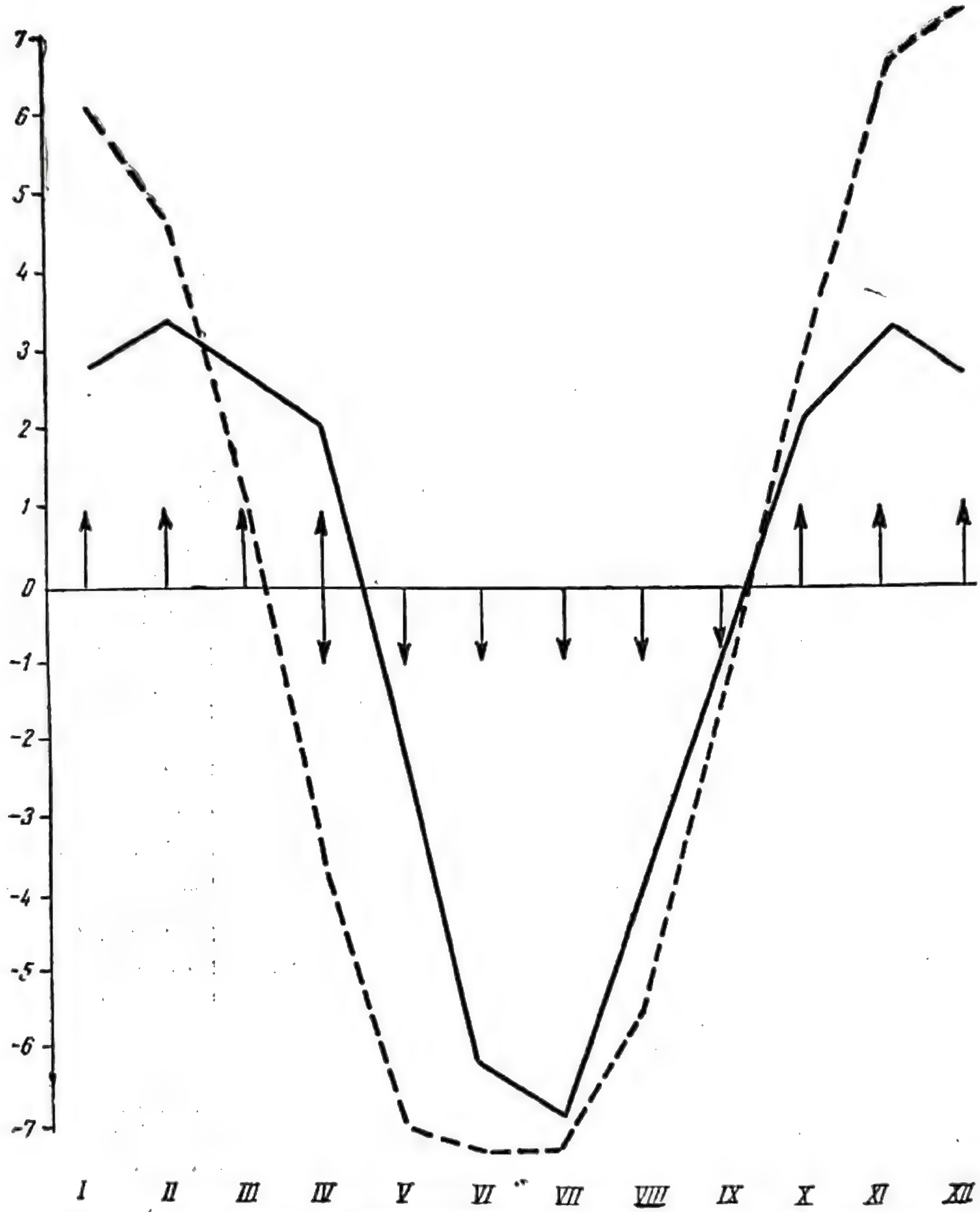

Abb. 1. Veränderung der Bodentemperatur zwischen den Tiefen 0,2 und 1,6 m
——— Obozerskaja; – – – – – Kherson.

Durchdringungstiefe der Temperatur (< 10°C) 3—4 m, Jahresamplituden 19—22°C in der Tiefe 0,2 m und 10—13°C in der Tiefe 1,6 m. In der Zone J_2 beträgt die Bodentemperatur 9—11°C, aktive Temperaturen dringen hier bis 4—5 m durch, und die Amplituden erreichen 21—24°C und 12—14°C. In der Zone J_3 sind diese Werte: 11—13°C, 5—6 m, und die Amplituden betragen 23—25°C und 13—15°C.

Die angeführten Angaben gestatten uns die Frage über die Klassifikation der Temperaturhaushalte des Bodens auf Grund des Beispieles des Zentralen Europäischen Teils der UdSSR zu betrachten.

Entsprechend der Richtung des Temperaturgradienten können wir 3 Typen des Bodentemperaturhaushaltes unterscheiden:

1. Radiationstyp (im jählichen Wärmezyklus dominiert der positive Temperaturgradient).
2. Typ des unstabilen Gleichgewichts der Bodentemperatur.
3. Typ der Insolation (im jährlichen Wärmezyklus dominiert der negative Temperaturgradient).

Nach dem Grad der Ausprägung des kontinentalen Klimas unterscheidet man folgende Subtypen:

1. Gemässigter mit Temperaturamplituden des Bodens in der Tiefe 0,2 m—15—20°C.
2. Kontinentaler mit Amplituden — 20—25°C.
3. Stark kontinentaler mit Amplituden — 25—30°C.

Man unterscheidet folgende Arten des Bodentemperaturhaushaltes:

a) Subarktischer. Jahrestemperatur in der Tiefe 0,2 m—4—5°C.
Durchdringungstiefe aktiver Temperaturen 1—2 m.
b) Kalter. Jahrestemperatur 5—7°C.
Durchdringungstiefe aktiver Temperaturen 2—3 m.
c) Kühler. Jahrestemperatur 7—9°C.
Durchdringungstiefe aktiver Temperaturen 3—4 m.
d) Warmer. Jahrestemperatur 9—11°C.
Durchdringungstiefe aktiver Temperaturen 4—5 m.
e) Sehr warmer. Jahrestemperatur 11—13°C.
Durchdringungstiefe aktiver Temperaturen 5—6 m.

Diese Klassifikation des Temperaturhaushaltes des Bodens ist eine vorläufige Klassifikation, und sie ist für das ganze Territorium der Sowjetunion nicht geeignet.

In Zukunft muss sie präzisiert und detailliert werden.

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ZUSAMMENFASSUNG

Es wird der Temperaturhaushalt verschiedener lehmiger Bodentypen, des Europäischen Teils der UdSSR charakterisiert.

Es wird gezeigt, dass:

a) der Temperaturhaushalt des Bodens, gemäss der geographischen, zonalen Lage, jeweils durch spezifische Besonderheiten gekennzeichnet ist, die sich von dem Temperaturhaushalt der Luft unterscheiden;

b) im Jahreswärmezyklus stellen sich in den Böden verschiedene, von ihrer Lage auf dem Meridian abhängende Temperaturgradienten ein, die einen wesentlichen Einfluss auf die Bodenbildungsprozesse ausüben. Eine Klassifikation des Temperaturhaushaltes der Böden wird vorgeschlagen.

SUMMARY

The temperature regime for various great soil groups of loamy texture from the European part of the USSR is presented.

It is shown that:

a) the geographical and zonal varieties of soil temperature regimes have their own peculiarities, as compared with the air temperature regimes;

b) in the annual soil heat cycle different temperature gradients arise. They are determined by the position on geographical meridians of the soils. These gradients essentially influence soil formation. A classification of soil temperature regimes is proposed.

RÉSUMÉ

Les régimes de température de différents types de sols limoneux situés dans la partie européenne de l'URSS sont caractérisés:

On démontre que:

a) Le régime de température des sols est caractérisé suivant la situation géographique zonale, par des particularités spécifiques, qui se distinguent des régimes de température de l'air;

b) en fonction de la position sur le méridien, des directions différentes du gradient de la température du sol se manifestent dans le cycle annuel qui exercent une influence essentielle sur le processus de la formation du sol. Une classification des régimes de température des sols est proposée.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

HEAT TRANSFER IN SOILS[1]

H. KOHNKE, GHAZI AL NAKSHABANDI[2]

THE IMPORTANCE OF HEAT TRANSFER IN THE SOIL

Heat transfer in the soil is of great importance both for practical and academic reasons. The rate of heat transfer affects the rate of soil warming up in spring and cooling down in the fall and its freezing rate and depth during winter. It affects soil temperature and its fluctuations and consequently the movement of water both in the vapor and the liquid phases. Soil temperature is a determining factor of plant growth, of microbe activity, of chemical reactions in the soil and consequently of the availability of plant nutrients. Temperature also affects the availability of water to plants. For instance the wilting point of a soil is lowered, as temperature is increased.

Heat transfer within the soil and at the soil-atmosphere boundary has a great influence on the microclimate.

A knowledge of the principles of heat transfer in soils is important in the engineering field as well as in agriculture. Examples of such applications are found in building construction, especially in areas of permafrost, in the dissipation of heat from underground electric power lines, in road building, the utilization of heat pumps, and in the protection of underground waterlines from freezing.

It is obvious that a full understanding of the factors involved is necessary for the management of heat transfer in soils.

THE NATURE OF HEAT TRANSFER IN SOILS

Heat energy may be transferred from one location in the soil to another in a variety of ways. These are:

1) conduction through mineral and organic constituents, and through water and air;

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[1] Journal Paper No. 2321, Purdue University Agricultural Experiment Station, Lafayette, Indiana, Contribution from the Department of Agronomy.

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2) latent energy transfer by change of the state of water, e.g. evaporation, condensation, freezing;

3) movement of water or air through the soil, e.g. percolating rainwater or melting snow;

4) convection of water or air;

5) radiation from one particle to the other.

Movement of air through the soil as well as convection and radiation are of minor importance. Quantitatively the outstanding mechanism of heat flow in the soil is probably conduction. Most of the discussion of this paper is devoted to it.

The conduction of heat through the soil is a function of the heat energy available, of the temperature gradient and the thermal conductivity of the soil. Thermal conductivity is defined as the time rate of transfer of heat by conduction through unit thickness, across unit area for unit difference in temperature. In case of soils it is best expressed as millicalories per second, per centimeter, per degree centigrade.

FACTORS AFFECTING HEAT TRANSFER IN SOILS

In the case of homogeneous material such as metals or minerals a definite thermal conductivity can be determined that will vary only with temperature and possibly with the axis of crystallization. In an unconsolidated heterogeneous body made up of a variety of components, conductivity is affected by many factors. The first of these are the thermal conductivities of the individual components. They are indicated in table 1.

The great differences between the conductivity of the components

Table 1

Thermal conductivity of some soil components

Soil component	Thermal conductivity in mcal/s. cm. deg C
Mineral soil particles	3—20
Ice	3—4
Soil organic matter	0.3—0.6
Water	0.3—1.4
Air	0.05

shows that their relative amounts and their relative location have a determinig influence upon the overall conductivity. Since soil grains touch each other only at points or very small areas the conductivity of a dry soil (0.2—0.6 m cal/s cm deg C) is many times smaller than that of the soil grains themselves. The conductivity of air is so small that its effect can be neglected. When soil is moistened its conductivity increases because water will form a contact between the soil grains. The amount of this increase depends on the area of contact, the thickness of the water layer and the temperature.

As the thickness of the water layer around the soil particles is a function of tension, thermal conductivity of soil must be expected to be a function of moisture tension.

The larger the individual mineral particles the less frequently is the flow of heat interrupted. On the other hand the larger the particles the fewer contacts there are per given volume of soil. The overall effect for sands of uniform size is a small increase in conductivity with the increase of particle size (Nakshabandi and Kohnke, 1964). This situation changes where particles of various sizes are mixed together as the small particles fill the pores between the large ones. Therefore thermal conductivity is increased. In a natural soil this relationship may not occur, because the small particles form aggregates and more pore space exists than in a sand.

The rate of temperature change from one point of the soil to another depends not only on the thermal conductivity but also on the heat capacity per unit volume of soil. This property is the thermal diffusivity (K), sometimes called temperature conductivity on thermometric conductivity. It is the ratio of the thermal conductivity (λ) to the volumetric heat capacity (C_v).

$$K=\frac{\lambda}{C_v}.$$

The greater the volumetric heat capacity the smaller is the amount of heat that reaches a point distant from the heat source. The volumetric heat capacity rises both with the bulk density of the soil and with its moisture content. From the agronomic point of view thermal diffusivity is more important than thermal conductivity as it determines the actual temperature fluctuation in the soil.

Both conductivity and volumetric heat capacity of soil rise with rising moisture content. If volumetric heat capacity rises faster than thermal conductivity, diffusivity decreases with increasing moisture content. This frequently happens in the wet range.

Soils in their natural structure have a higher thermal conductivity than when they are broken up. This is true when they are compared in dry or in moist condition. The main reason for this is that many of the intimate contacts between individual particles and between aggregates are destroyed. Soils that are well aggregated and contain much pore space have a lower thermal conductivity than poorly aggregated soils or soils in single grain structure. Also the presence of organic matter reduces thermal conductivity of soils. Its thermal conductivity is low, and it also contributes to aggregation of the soil and consequently to a lowered bulk density, which in turn reduces thermal conductivity.

Moisture has by far the greatest influence upon the thermal conductivity of soil. Many workers have shown that thermal conductivity of soils increases with the increase in moisture content. Attempts have been made to express the thermal conductivity of a soil as a function of its moisture content, but with little success. It has been clearly established that a small increment of moisture increases conductivity of a sandy soil much more than that of a medium textured soil. The same amount of water hardly raises the conductivity of a clay soil at all.

From the previous discussion it appears likely that the thickness of the water film around the soil particles, by bridging the gap from soil grain to soil grain should have a determining influence upon the amount of conduc-

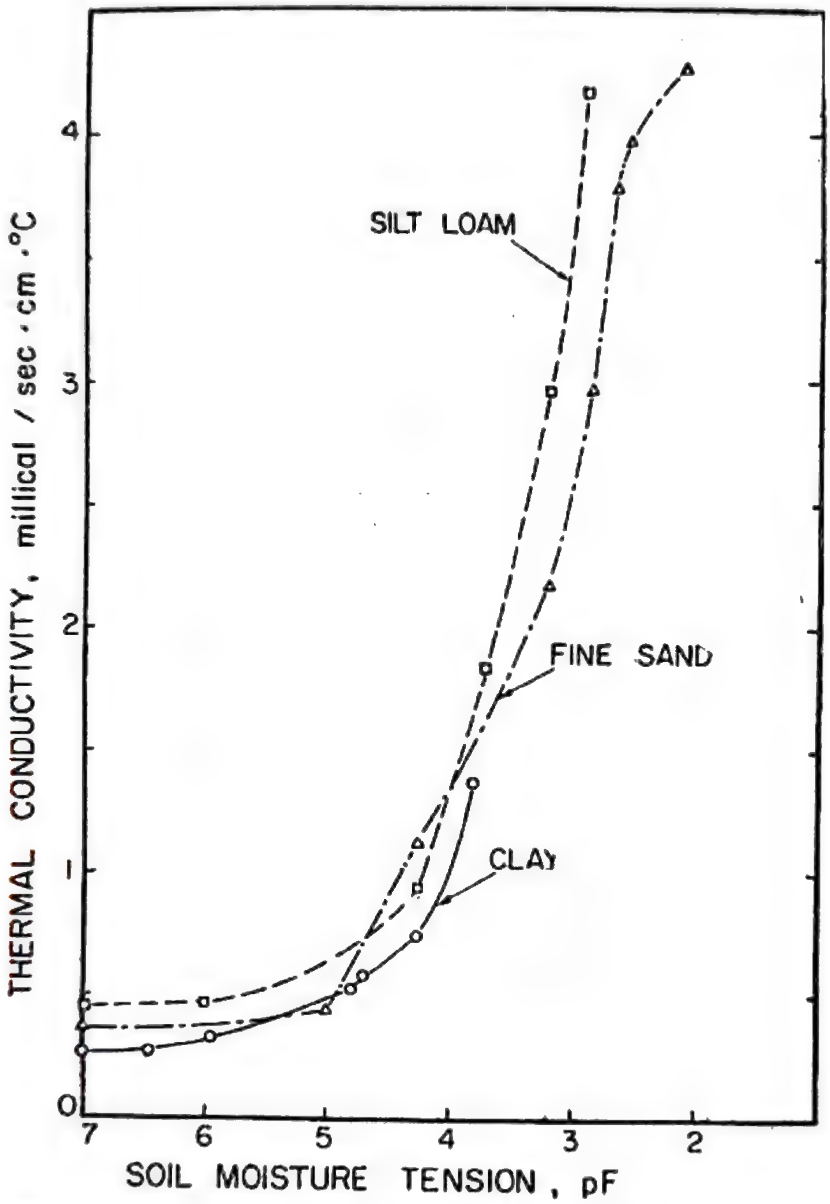

Fig. 1. The effect of soil moisture tension on the thermal conductivity of three soils.

tivity. The thickness of the water film on the other hand is dependent on the ratio between the water content and the specific surface. At 10 per cent water (by weight) a sandy loam of 40 sq.m./g specific surface has a layer of about 10 molecules of water. At the same moisture content the layer around a loam of 80 sq.m./g specific surface is only 5 molecules thick, while the water layer of a silty clay loam of 200 sq.m./g specific surface is a mere 2 molecules

thick. It seems obvious that such a thin layer can contribute only very little in conducting heat from one particle to the next.

In a soil of negligible salt content the thickness of the water layer around the soil particles is related to the moisture tension. Since the thickness of the water layer is of determining influence upon conductivity it seems probable that there should also be a relation between thermal conductivity and the soil moisture tension. This is evidenced by work of Nakshabandi and Kohnke (1965) with three mineral soils, a clay soil, a silt loam and a washed fine sand. Figure 1 shows that this relation is similar for these entirely different soils. Obviously the three curves are not identical because other factors beside the thickness of the moisture film have an influence upon the magnitude of the thermal conductivity. It is interesting to note that at about pF 4.5 the rate of thermal conductivity begins to increase much faster than at higher tension. In the dry range (pF 7—pF 4.5) the thickness of the water layer increases only little while at lower tension it increases much faster.

The importance of water film thickness upon thermal conductivity is evidenced in figure 2. In spite of the great differences of the three soils the curves are similar. It appears that, as the water films become thicker, the same film thickness increases the thermal capacity of the silt loam more than that of the fine sand. Figure 3 shows the relationship between water content and thermal conductivity of the same three soils. This is the method in which thermal conductivities of soils are most frequently reported. The great divergence of the curves clearly shows the impossibility of estimating thermal conductivities from moisture contents.

MANAGEMENT OF HEAT TRANSFER IN SOILS

Heat transfer in soils affects plant growth through its effect upon temperature and temperature fluctuations and the many consequent reactions; therefore, proper management of heat transfer is of importance to the farmer. This can be accomplished by modifying the factors that influence heat transfer.

Since percolating water, convection of air or water and radiation from particle to particle are of minor importance to heat transfer in soils, emphasis has to be given to the modification of the factors that affect thermal diffusivity. Thermal diffusivity is proportional to thermal conductivity and inversely proportional to heat capacity per unit volume. Thermal conductivity changes with moisture content, structure and organic matter content. While it also changes with texture this is seldom subject to modification by management. Heat capacity per unit volume depends on the weight per unit volume and the specific heat of the solid particles of the soil, both mineral and organic, and on the amount of water present. The looser the soil, the higher its organic matter content and the drier it is, the lower is its heat capacity.

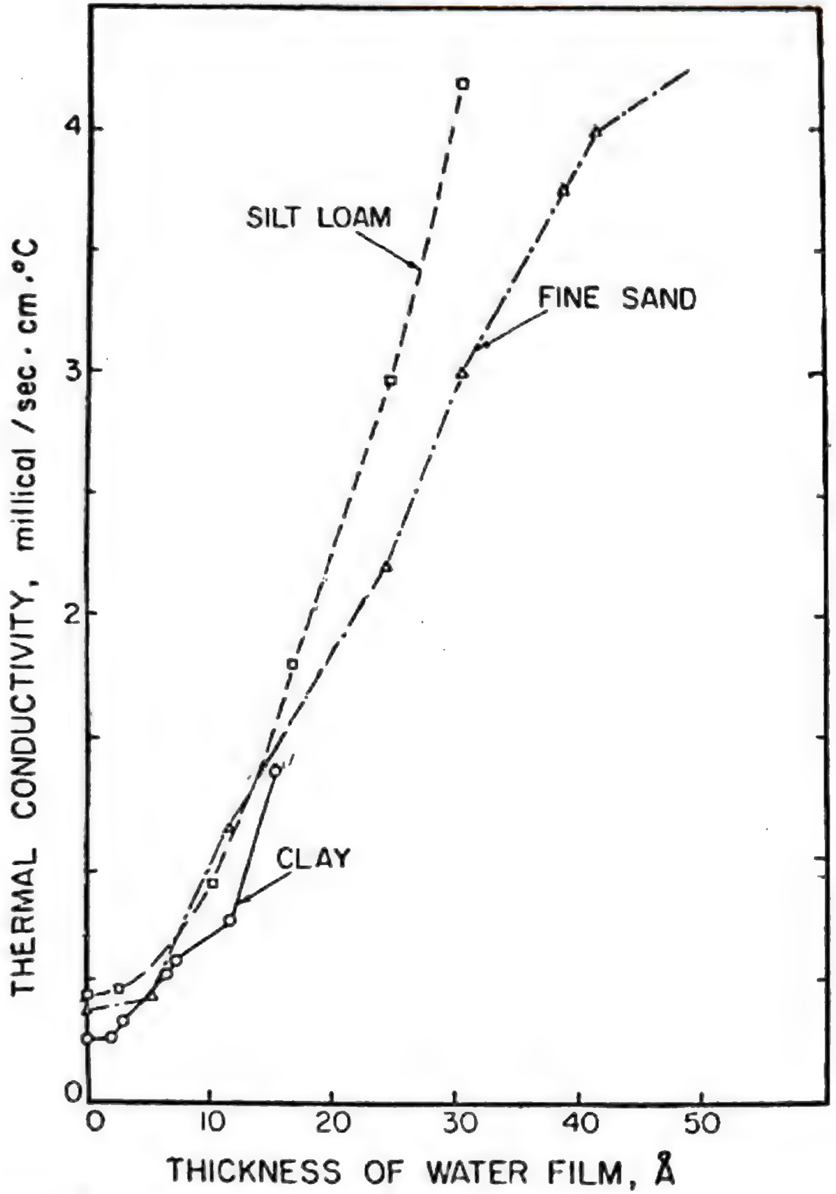

Fig. 2. The effect of water film thickness on the thermal conductivity of three soils.

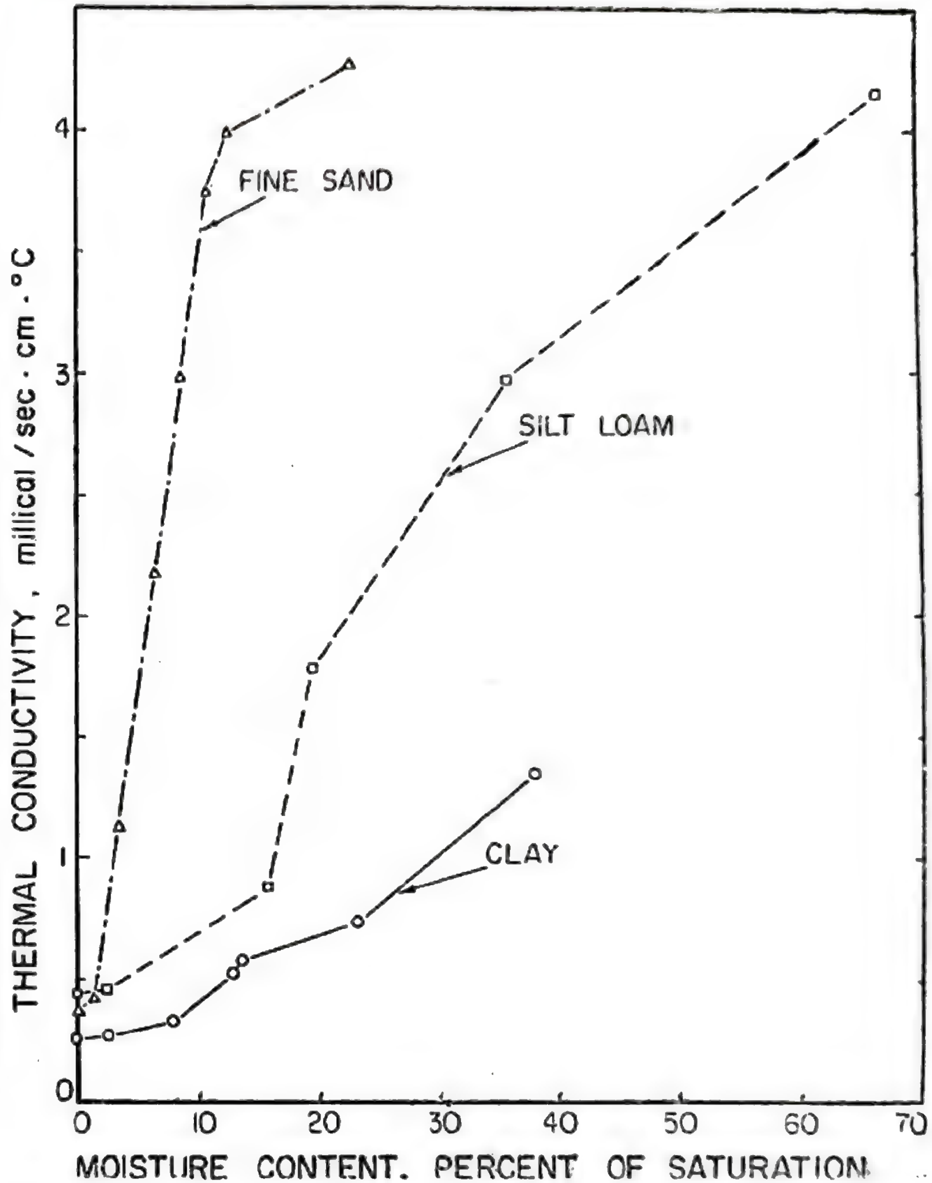

Fig. 3. The effect of water content on the thermal conductivity of three soils.

If we want to increase the rate of heat transfer in the soil we have to find a combination between conductivity and heat capacity that results in the highest thermal diffusivity. In other words we have to increase the conductivity by compacting the soil and by maintaining a high moisture content, being careful not to raise the heat capacity too much. The optimum combination of moisture content is reached at a tension between pF = 2.5 and 3.0. Generally the moisture content of the soil is so high in the spring that removal of water by drainage or evaporation increases thermal diffusivity. While the optimum degre of compaction can so far not be stated quantitatively, in actual practice soils are cultivated to decrease the rate of heat transfer, where this seems advisable, while they are compacted by rolling where an increase in diffusivity is desired. The latter procedure is used in cool climates on muck soils in order to increase the effective growing season (Pessi, 1956).

MEASURING HEAT TRANSFER IN THE SOIL

Probably the main reason that heat transfer in soils has not received the same attention by research workers as other physical properties is the difficulty of measurement. Topping the list of problems is the water transfer that is induced by temperature differences that are needed to create heat movement. This results in a change in conductivity and heat capacity and in heat transfer by evaporation at the place of high temperature and condensation at the place of low temperature.

The thermal needle that was originally proposed by Schleiermacher (1956) and improved by several workers (Stalhane and Pyk, 1931; Hooper and Leeper, 1950; Hooper and Chang, 1953; Nakshabandi and Kohnke, 1965) makes it possible to measure thermal conductivity in a very short time and with a small temperature gradient so that the inherent errors of the determination are largely eliminated. The thermal needle consisting of a thin metal tube containing an electric heating wire in its center is placed in the soil. As a measured amount of heat energy is supplied to this wire the temperature of the tube is measured with a thermocouple. The greater the rate of temperature rise the smaller is the conductivity of the surrounding medium. It is standardized in media of known thermal conductivity.

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SUMMARY

The nature of heat transfer in soils and the factors affecting it are discussed. Thermal conductivity is the most important form of heat transfer in soils. Its rate of increase with a decrease in soil moisture tension is similar for a clay soil, a silt loam and a washed fine sand. In the higher tension range there is good agreement between the thickness of the water film around the soil particles and thermal conductivity of the different soils. The relation between soil moisture content and thermal conductivity is completely different for the three soils.

Some of the principles of managing and of measuring heat transfer in soils are presented.

RÉSUMÉ

Sont discutés la nature du transfert de la chaleur dans les sols et les facteurs qui l'influencent. La conductibilité thermique est la principale forme du transfert de la chaleur dans les sols. Son taux d'augmentation, avec une diminution de la tension de l'eau est similaire pour un sol argileux, un limon silteux et un sable fin délavé. Aux tensions élevés il y a une bonne concordance entre l'épaisseur de la pellicule d'eau autour des particules de sol et la conductibilité thermique des divers sols.

Le rapport entre l'humidité du sol et la conductibilité thermique est tout à fait différente pour les trois sols.

Sont présentés quelques-uns des principes utilisés pour régler et mesurer le transfert de la chaleur dans les sols.

ZUSAMMENFASSUNG

Es wurde das Wesen der Wärmeleitung in Böden und die sie beeinflussenden Faktoren besprochen.

Die Wärmeleitfähigkeit ist die wichtigste Form der Wärmeleitung in Böden. Ihre Geschwindigkeitszunahme bei einer Abnahme der Bodenwassersaugspannung ist gleichartig für einen Tonboden, einen schluffigtonigen Lehm und einen ausgewaschenen Feinsandboden. Es besteht eine gute Übereinstimmung zwischen der Dicke des Wasserfilms um die Bodenkörner und die Wärmeleitfähigkeit der verschiedenen Böden, in den höheren Saugspannungsordnungen.

Das Verhältnis zwischen dem Bodenwasserprozentsatz und der Wärmeleitfähigkeit ist in den drei Böden vollständig verschieden. Es werden einige Grundsätze für Wärmeleitung und Wärmemessung in Böden dargestellt.

DISCUSSION

M. KUTÍLEK (Socialist Republic of Czechoslovakia). Which method have you used for specific surface determination? The ethylene-glycol method gives lower values than the adsorption-water-vapor method (BET eq.) when we are dealing with expanding lattice minerals in the clay fraction (e.g. montmorillonites). As we are dealing with the interaction between the solid phase and water, the adsorption water vapor method is more precise.

H. KOHNKE. We used the ethylene-glycol method.

M. K. MELNIKOVA (U.S.S.R.). How was the determination of the water film thickness made?

H. KOHNKE. The thickness of the water film was calculated from the moisture content and the specific surface.

J. W. HOLMES (Australia). Did Dr. Kohnke attempt to calculate the thermal conductivity from the thermal conductivities of its components, both mineral and water?

H. KOHNKE. The conductivity was determined with a thermal needle. The needle was heated and its temperature determined. The heat flow was radial.

M. B. RUSSELL (U.S.A.). Were the thermal conductivity measurements made in such a way as to allow or to prevent the simultaneous flow of heat and liquid water or water vapor?

H. KOHNKE. The measurements required only 10 minutes and a very small thermal gradient. Therefore the flow of water was minimized.

I. 22

DAS WESEN DER STRUKTURBILDUNG IN BÖDEN

N. A. KATCHINSKY [1]

Alle Phasen des Bodens (feste, flüssige, gasförmige) und seine Lebewesen nehmen an der Strukturbildung teil. Hauptsächlich aber besteht die Bodenstruktur aus den festen mechanischen Elementen, die verschiedene Aggregate bilden. Der Prozess der mehr oder weniger intensiven Aggregation der mechanischen Elemente charakterisiert die *strukturbildende Fähigkeit des Bodens*. Dieser Prozess verläuft infolge der Koagulation der Kolloide, der Verbindung der mechanischen Elemente durch kolloidale Hüllen, des Zusammenklebens der Bodenteilchen unter dem Einfluss der van der Waalsschen Kräfte, der Restvalenzen und auch durch die Wasserstoffbindungen in Huminsäuren und Humaten. Die Aggregation der mechanischen Elemente ist durch Adsorption des Wassers, Kationen und Mikroorganismen, kapillare Erscheinungen in festen und flüssigen Bodenphasen, das Pflanzenwurzelnetz und Pilzhyphen, die Krümel und Einzelkörner umspinnen und in dieselben eindringen, so wie durch Temperaturschwankungen begünstigt. Im Zusammenwirken aller dieser Prozesse, die in verschiedenen Böden vielfältig sich gestalten, entsteht die Bodenstruktur.

Daraus folgt, dass *die Bodenstruktur eine für jeden Boden und seine Horizonte charakteristische Anordnung der Bodenaggregate von verschiedener Grösse, Form, Porosität, mechanischer Festigkeit und Wasserbeständigkeit darstellt*.

Viele Arbeiten sind der Frage über die Bodenstruktur gewidmet. In Russland und in der Sowjetunion wurden spezielle Untersuchungen der Bodenstruktur von Kostychew. Wiljams, Gedroiz, Sokolowsky, Tiulin, Katchinsky, Antipow-Karataew, Werschinin durchgeführt. In den anderen Ländern sind mit dieser Frage auch viele hervorragende Forscher beschäftigt, wie Schloesing, Wollny, Mitscherlich, Kubiena, Kuron in Deutschland; Russel in England; Hissink in Holland; Sigmond in Ungarn; Bouyoucos, Richards und Baver in der USA; Demolon in Frankreich; Marshall in Australien; Puri in Indien und Pakistan; Smoluchowsky in Polen; Mattson in Schweden; Wiegner in der Schweiz und Stebut in Jugoslawien und andere.

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[1] Moskauer Universität, UdSSR.

Zur Zeit ist es anerkannt, dass die Fruchtbarkeit der Böden mit feiner Textur (mittel-lehmiger, stark-lehmiger und toniger) besonders von ihrer Struktur abhängig ist (bei gegebenen klimatischen und Bodenverhältnissen), da der Wasser-, Luft- und Ernährungshaushalt des Bodens durch den Charakter seiner Struktur bestimmt ist. Die landwirtschaftlichen Kulturen liefern immer einen höheren Ertrag auf einem Strukturboden als auf einem strukturlosen Boden *bei derselben Agrotechnik*.

Deshalb kann man in Hinblick auf schwere Böden (ihrer Korngrössenzusammensetzung nach) berechtigt sagen, dass der *Kulturboden ein Strukturboden ist.*

Man muss jedoch zwei Begriffe betreffs der Bodenstruktur unterscheiden, und zwar: Bodenstruktur als morphologisches Merkmal und Bodenstruktur im agronomischen Sinne.

Als morphologischen Merkmal eines bestimmten Bodentypes kann jede Bodenstruktur als eine charakteristische und gut ausgeprägte anerkannt sein, sei es Krümelstruktur (für den humus-akkumulativen Horizont A_1 der gewöhnlichen und fruchtbaren Schwarzerden); Nussstruktur (für Horizont A_2 der grauen Waldböden und für den Horizont B_1 der rasen-podzoligen Böden oder Horizont C_1 der Kastanienböden); Blattstruktur (für Horizont A_2 der podsoligen Böden); Kolonnenstruktur (für den illuvialen Horizont der Alkaliböden) und Plattenstruktur (für feinerdige alluviale Böden) und so weiter.

Als positive Struktur im agronomischen Sinn gilt nur die Krümelstruktur mit Aggregaten von 0,5—1—3—5—10—15—20 mm im Durchmesser, denn, solche Struktur ist *porös, mechanisch stabil und wasserbeständig*. Sie erhält sich langdauernd bei wiederholten Bodenbearbeitungen und auch nach künstlichen und natürlichen Anfeuchtungen.

Man soll zwei Kategorien der Wasserbeständigkeit der Aggregate unterscheiden:

a) die von irreversiblen koagulierten Kolloiden, besonders organischer Kolloide mit Ca- und Fe-Kationen, bedingt ist, und

b) die durch dichte Verpackung der mechanischen Elemente verursacht und von der im Aggregat stark entwickelten unaktiven Porosität begleitet ist, wenn alle Poren des feuchten Bodens mit gebundenem und fein kapillarem Wasser ausgefüllt sind (Katchinsky, 1947). Die erste Kategorie der Wasserbeständigkeit ist agronomisch günstig, die zweite aber (bei dichter Verpackung der mechanischem Elemente), die man bei dem säulenförmigen Horizont der Alkaliböden und dem illuvialen Horizont B_2 der rasen-podsoligen Böden trifft, ist agronomisch ungünstig. Für diese Struktur (obwohl sie wasserbeständig ist) ist charakteristisch, dass Wasser zum grössten Teil den Pflanzen nicht zugänglich ist. Solch eine Struktur besizt ungenügende Mobilität und schwache biologische Aktivität. Es sei daran erinnert, dass die Haarwurzeln in Poren kleiner als 0,01 mm und die Bakterien in Poren kleiner als 0,003—0,001 mm nicht eindringen können.

Ausserdem ist die Wasserbeständigkeit der Bodenstruktur sehr dynamisch. Während der Vegetation verändert sie sich in Abhängigkeit von der Bodenfeuchtigkeit und Dauer seiner Anfeuchtung (Abb. 1) und auch vom

Entwicklungsgrad der biologischen Prozesse in weiten Grenzen. Darum ist es nötig, die Bodenstruktur während der Vegetation einige Male zu kontrollieren und die Analyse den Bodenproben nur bei ihrer natürlichen Feuchtigkeit durchzuführen.

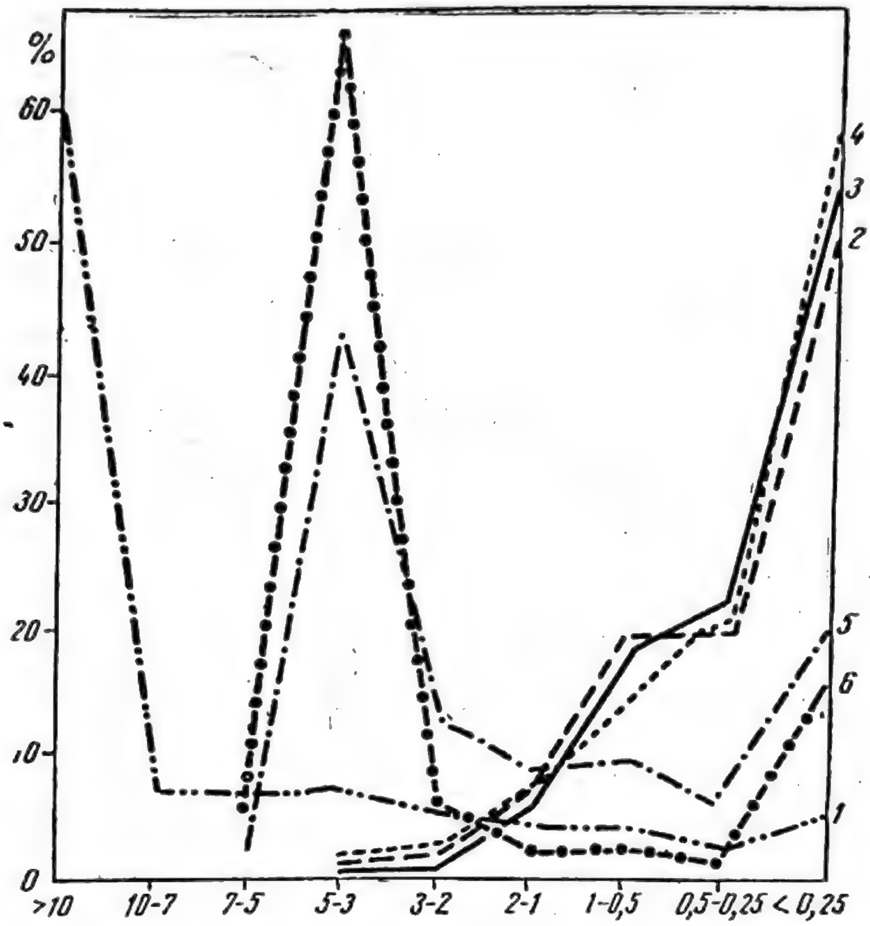

Abb. 1. Aggregatzusammensetzung des Bodens in Abhängigkeit von der Befeuchtung der analysierten Probe — in % des trockenen Bodens Südliche Schwarzerde, stark-lehmig; Horizont A_1
Trockenes Durchsieben: *1* — lufttrockener Boden; *Feuchtes Durch. sieben*: *2* — absolut trockener Boden; *3* — lufttrockener Boden; *4* — Boden bei der maximal hygroskopischen Feuchtigkeit; *5* — Boden mit Wasser während 3 Tage kapillar gesättigt; *6* — Boden mit Wasser während 40 Tage kapillar gesättigt

Neben der Makrostruktur (grösser als 0,25 mm) ist auch die Mikrostruktur (kleiner als 0,25 mm) für die Einschätzung der Bodeneigenschaften von grosser Bedeutung. Sie muss auch wasserbeständig und porös sein. Die beste Mikrostruktur entspricht einer Krümelgrösse 0,25—0,05 mm und 0,05—0,01 mm.

Diese wasserbeständige Mikrostruktur (z.B. in Rot- und Gelberden) verleiht den Makroaggregaten positive Eigenschaften. Ausserdem erhöht

sie unmittelbar die Wasserkapazität des Bodens, verbessert seine Wasser- und Luftdurchlässigkeit, als wenn sie die Rolle der Sandkörner und des Grobschluffs spielte. Zum Unterschied von den Sandkörnern und Grobschluff besitzen die Mikroaggregate Porosität, in welcher Wasser, Mikroorganismen und Haarwurzeln konzentriert sind. Die Mikroaggregate unter 0,01—0,005 mm sind weniger nützlich. Das ist ein passiver Bodenteil. Sie erschweren die Wasser- und Luftdurchlässigkeit des Bodens, bedingen seine Verdichtung bei der Bearbeitung so wie seine grosse Verdunstungsfähigkeit und andere negative Eigenschaften.

Man muss auch bemerken, dass es keine Standardgrössen der optimalen Struktur für alle Klima- und Bodenzonen gibt. Je höher die Wasserversorgung der Zone ist, desto grösser muss der optimale Querschnitt der Strukturaggregate sein (ungefähr 10—20 mm), um die beste Wasser- und Luftdurchlässigkeit zu versorgen, und für vermoorte Gelände auch die Wasserabgabe des Bodens.

Umgekehrt, in den trockenen Zonen, wo es nötig ist, Wasser zu erhalten, und wo die Bodendurchlüftung übermässig ist, sind die optimalen Grössen der Aggregate den feinen Krümeln und Körnern sehr nah (1—10 mm).

Die Struktur ist in Böden von feiner Textur — mittleren und schweren Lehm- und Tonböden — am besten ausgeprägt. Das ist mit dem Vorhandensein mechanischer Elemente kolloidaler Dimension ($<0{,}2$—$0{,}1\,\mu$) verbunden. Daraus ist es verständlich, dass die Eigenschaften der Kolloide, die Gesetzmässigkeiten ihres Verhaltens in Lösungen und in erster Linie ihr Koagulationsvermögen, d.h. der Übergang aus Sol- in Gelzustand (was zur Vergrösserung der Teilchen, Verminderung der Energievorräte und Abscheidung dieser Teilchen führt) allen Theorien der Strukturbildung in Böden zugrunde liegen müssen. In der Bodenkunde sind die Untersuchungen von Gedroiz am besten bekannt, die später von seinen Anhängern entwickelt und ergänzt wurden. Die Koagulation beginnt mit der Bildung der primären Mikroaggregate. Da die Koagulation der kolloidalen Teilchen im isoelektrischen Punkt selten beobachtet wird, können primäre Mikro aggregate positive oder negative Ladung erhalten und bei verschiedener Ladung sich gegenseitig anziehen und Mikroaggregate der zweiten, dritten und höherer Ordnung bilden, einschliesslich bis zu kleinen Körnern. Dieser Prozess ist schematisch in Abbil dung 2 gezeigt.

Noch häufiger beobachtet man die Koagulation der Kolloide unter dem Einfluss der Elektrolytionen. Die beste Struktur bildet sich im Falle, wenn an diesem Koagulationsprozess Ca^{2+} und Fe^{3+} so wie Huminsäuren teilnehmen, die fähig sind Wasserstoffbindungen zu bilden.

Mikroaggregate und während der Koagulation gebildete Aggregate können sich auf verschiedenem Wege festigen. In den letzten Jahren haben Untersuchungen gezeigt, dass die mechanische Stabilität und Wasserbeständigkeit der Aggregate als Resultat der chemischen Prozesse, die im Boden bei sich verändernden Wasser- und Lufthaushalten ablaufen, entstehen und steigern können (Katchinsky, Mosolowa 1950—1958; Gorbunow und Kowalew 1953). Die typische Struktur in dieser Hinsicht ist die Einzelkornstruktur der zentralen Aueböden und vieler Humus- und Sumpfböden mit abwechselnder Überfeuchtung und Austrocknungsperioden.

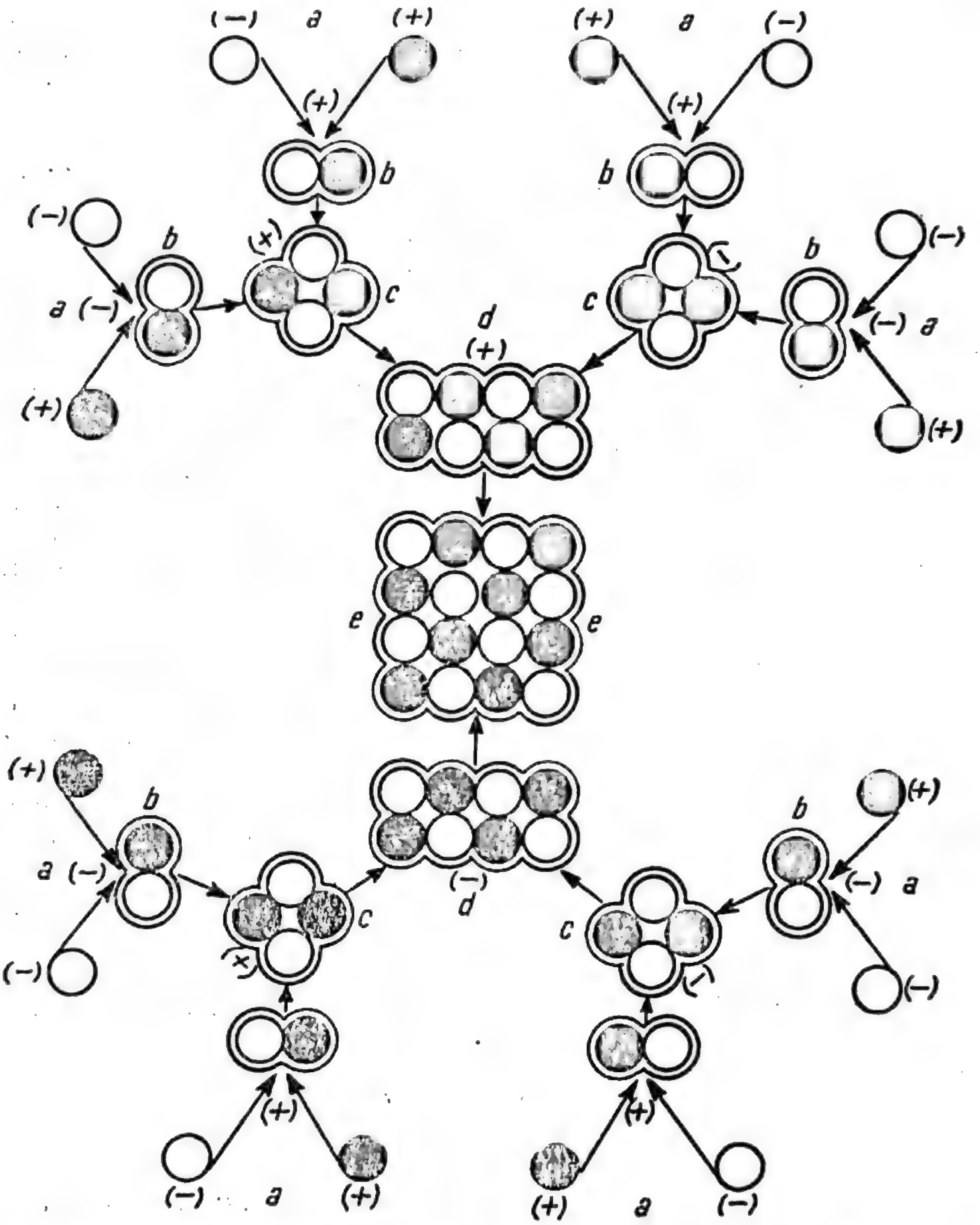

Abb. 2. Scheme der Mikroaggregatsbildung bei gegenseitiger Koagulation der Kolloide: *a* — Ausgangs-Kolloidalteilchen; *b* — Mikroaggregate der ersten Ordnung; *c* —Mikroaggregate der zweiten Ordnung; *d* — Mikroaggregate der dritten Ordnung; *e* — Mikroaggregate der vierten Ordnung.

Während der Überfeuchtung des Bodens entstehen Reduktionsprozesse, die von der Bildung löslicher Eisenoxydulverbindungen begleitet sind, die zusammen mit der Bodenlösung sich in die Aggregate infiltrieren. Während der Dürreperiode sind die ausgetrockneten Bodenschichten infolge des Absenkens von Grund- und Senkwasser durchlüftet; Eisenoxydul übergeht in unlösliche Formen des Eisenoxyds, die die Aggregate zementieren.

Die Strukturteilchen können sich beim Übergang von $Ca(HCO_3)_2$ in $CaCO_3$ und $CaHPO_4$ in $Ca_3(PO_4)_2$ im Boden festigen.

In optimal befeuchteten Böden wirken kapillare (Meniskus) Kräfte und gebundenes Wasser als Faktoren der Strukturbildung. Die Wasserbeständigkeit der Aggregate steigt beim Verkleben mechanischer Elemente mit dem Schleim verschiedener Bakterien aus der Gruppe der Knöllchenbakterien, *Azotobacter* und *Pseudomonas*, mit ihrer Befestigung von Pilzhyphen (z.B. *Trichoderma lignorum*) und den Pflanzenwurzeln (Katchinsky 1934, Kanivez 1939, Mischustin 1943, Gelzer 1940 und andere).

Eine besonders positive Rolle spielen in diesem Prozess mehrjährige *Gräser. Unter Bedingungen, in denen sie sich gut entwickeln, strukturieren diese Gräser den Boden besser als alle* andere Pflanzen durch ihr mächtiges und gut venzweigtes Wurzelsystem und auch als Material für die Humusbildung. Seit Darwins Arbeiten ist die Rolle der Regenwürmer in der Strukturbildung des Bodens bekannt.

Die Regenwürmer verarbeiten den Boden in ihrem Magentraktus und scheiden ihn verklebt mit Magensaft als poröse Krümel aus (Koprolithen).

Die Bodenaggregate sind bei der abwechselnden Überfeuchtung und Austrocknung des Bodens und auch bei seinem Durchfrieren während der optimalen Anfeuchtung gebildet.

Die von uns genannten Prozesse der Bodenkrümelung wirken immer im Zusammenhang, Die Teilung dieser Prozesse, wie es in diesem Artikel geschehen ist, kann man nur in dem Sinne verstehen, dass in jedem konkreten Falle der Strukturbildung der Böden ein oder der andere Prozess oder einige von ihnen vorherrschen.

In den letzten Jahrzehnten gewinnt die Frage der künstlichen Bodenkrümelung durch Polymere eine grosse Aufmerksamkeit, aber diese Frage wird in diesem Artikel nicht erörtert.

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ZUSAMMENFASSUNG

Der Verfasser definiert die Bodenstruktur als die Gesamtheit von Aggregaten verschiedener Dimension, Form, Porosität, mechanischer und Wasserbeständigkeit, die für jeden Boden und seine Horizonte charakteristisch sind.

1. Die Bodenstruktur wird von zwei Standpunkten aus betrachtet:
   a) als ein bodenmorphologisches Kriterium;
   b) als ein bedeutender Faktor der Bodenfruchtbarkeit bei Lehm- und Tonböden.

Eine landwirtschaftliche stabile Struktur muss krümelig-körnig, elastisch-stabil, wasserbeständig und porös (Porosität > 40% des Aggregatvolumens) sein:

2. Es wird angenommen, dass die Wasserbeständigkeit der Aggregate, ihrer Natur nach, zweierlei Art ist:
   a) verbunden mit einem erheblichen Ausmass inaktiver Porosität;
   b) verbunden mit einer irreversiblen Koagulation der Bodenkolloide.

Nur die letzere ist für die Bodenfruchtbarkeit wertvoll.

Im Bericht werden die verschiedenen Rollen der Makro-bezw. der Mikrostruktur nach-

gewiesen. Die Eigentümlichkeiten der Bodenstruktur in verschiedenen bodenklimatischen Zonen werden aufgeklärt. Koagulation ist die Grundlage der Strukturbildung, doch spielen chemische, physikalische und biologische Faktoren dabei eine wesentliche Rolle. Auf Grund der Kenntnisse über die Hauptfaktoren der Strukturbildung werden die Art und die Eigenschaften verschiedener Bodenstrukturtypen, sowie die Methoden zu ihrer Verbesserung im Hinblick auf die Erhöhung der Bodenfruchtbarkeit bestimmt.

SUMMARY

Soil structure is defined by the author as a totality of aggregates of various dimensions, forms, porosity, mechanical and water stability, characteristic of each soil and its horizons.

1. The soil structure is considered in two ways:
   a) as a soil morphological criterion
   b) as an important factor of soil fertility for loamy and clay soils.

An agronomically stable structure must be crumby-granulary, elastic-stable, water-stable and porous (porosity > 40% of the aggregates volume).

2. The nature of the water-stability of aggregates is considered to be of two kinds;
   a) Connected with considerable inactive porosity;
   b) Connected with irreversible coagulation of soil colloids. Only the last kind is valuable for soil fertility.

In the report the different parts played by macro- and microstructure are shown. The peculiarity of soil structure in different-soil-climatic zones is elucidated. Coagulation is the base of structure formation, but chemical, physical and biological factors play in it an essential part. Knowing the main factors of structure formation, the character and properties of different types of soil structure and the methods of its improvement for an increase in soil fertility are determined.

RÉSUMÉ

L'auteur définit la structure du sol comme une totalité d'agrégats de dimensions, formes porosités, stabilité mecanique et à l'eau variées, caractéristique pour chaque sol et pour ses horizons.

1. La structure du sol est considérée de deux manières:
   a) comme un critérium morphologique du sol.
   b) comme un facteur important de la fertilité du sol pour les sols limoneux et argileux.

Une structure stable du point de vue agronomique doit être grumeleuse-granulaire, élastique-stable, stable à l'eau et poreuse (porosité > 40% par rapport au volume de l'agrégat).

2. La nature de la stabilité à l'eau des agrégats est considérée comme etant de deux espèces:
   a) par rapport à une porosité inactive considérable;
   b) par rapport à une coagulation irréversible des colloïdes du sol.

Cette dernière seulement est importante pour la fertilité du sol. La communication montre les différents rôles joués par la macrostructure et la microstructure et explique aussi les particularités de la structure du sol dans les différentes zones climatiques. La coagulation est la base de la formation de la structure, mais les facteurs chimiques, physiques et biologiques y jouent un rôle essentiel. Le caractère et les propriétés des divers types de structure du sol et les méthodes d'amélioration en vue d'augmenter la fertilité du sol sont déterminés par la connaissance des principaux facteurs qui interviennent dans la formation de la structure du sol.

DISKUSSION

P. BRUIN (Netherlands). 1. Determination method of water stable aggregates.

2. Importance of these figures as to crop yields. Our experience is that especially for heavy soils the figures of water stable aggregates are only of little importance for the prediction of yields. The action against mechanical deformation is of no importance.

N. A. KATCHINSKI. 1. Die Wasserbeständigkeit der Aggregate wurde nach N. A. Sawwinow's Feuchtsiebmethode des Bodens und durch Befeuchtung der Aggregate in stehendem Wasser nach der Methode von P. I. Andrianow bestimmt.

2. Die in der Mitteilung dargelegten Schlussfolgerungen sind auf vielfältigen Versuchen begründet, welche mit Böden aus verschiedenen Bodenzonen der UdSSR im Feld und im Laboratorium durchgeführt wurden.

Unseren Beobachtungen zufolge, äussert sich die positive Wirkung der Bodenstruktur auf seine physikalischen und anderen Eigenschaften, sowie auf die Erträge der landwirtschaftlichen Kulturen am stärksten bei Böden mit feiner Textur: bei mittleren und schweren Lehmböden und Tonböden.

Auf leichten Böden — Sandböden, lehmigen Sandböden und sandigen Lehmböden — wird die Rolle der Struktur geringer, weil diese Böden von Natur aus positive physikalische Eigenschaften aufweisen und ihre Struktur schwach ausgeprägt ist.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 23

HEAT OF WETTING OF ORGANO-MONTMORILLONITE COMPLEXES [1]

JACOB W. KIJNE, S. A. TAYLOR [2]

Two types of reactions have been found to occur between organic compounds and clay particles. Gieseking (1939) showed that organic ions enter into cation-exchange reactions with the clay minerals, particularly montmorillonite. Somewhat later, Bradley (1945) and MacEwan (1946) proved that the nonionic organic molecules of polar character could also be adsorbed by the clay minerals. The inorganic cations present on the surfaces of the clay minerals are not necessarily displaced by the adsorption of the organic molecules.

Hydrogen bonding has been proposed as a possible means by which the polar organic molecules are held to clay surfaces. Both Bradley and Mc Ewan concluded that organic molecules are held to the clay surfaces through a weak C—H...O bond, the oxygen being in the clay mineral surface. Based on x-ray diffraction studies, Emerson (1956) has suggested hydrogen bonding between carboxyl groups of the organic material and the edge atoms of the two clay crystals. He hypothesized a series of hydrogen bonds to the edge octahedral layers of clay mineral. Greenland (1963), using infrared analyses of polyvinyl alcohols, concluded that the attachment was probably through hydrogen bonding between hydroxyl groups of the alcohol and oxygens of the clay surface. Tensmeyer et al. (1960) showed that significant changes occur in the carbonyl stretching frequency when ketones are adsorbed on Ca montmorillonite, thus suggesting that carbonyl groups may be involved in adsorption. Hydrogen bonding between the double-bonded oxygen of a carbonyl group and a clay crystal was demonstrated by Kohl and Taylor (1961). New support for C—H...O interaction based on changes in the C—H stretching frequency has recently come from R. Tettenhorst et al. (1962).

[1]. The research reported herein was done in co-operation with the twelve Western States and the U.S. Department of Agriculture, Agricultural Research Service, as a part of Regional Research Project W-66. Published with the approval of the Director of the Utah Agr. Exp. Sta., Logan, as Journal Paper No. 394.

[2]. Research Associate and Professor of Soil Physics, respectively, Utah State University Logan, U.S.A.

EXPERIMENTAL METHODS

Montmorillonite No. 26 (bentonite from Clay Spur, Wyoming) was saturated with hydrogen and calcium by repeated flocculating in dilute hydrogen chloride and calcium chloride solutions. Each flocculation was followed by separation in a centrifuge and washing with deionized water until the suspension was dispersed again.
Several organic compounds were subsequently adsorbed on portions of the H and Ca bentonites. The compounds used were isopropyl acetate, amylbutyrate, 4-methyl-2-pentanone, methyl benzoate, ethyl benzoate, and ethyl-methyl ketone. Samples were prepared by placing a measured quantity of the adsorbent with 30 ml of the adsorbate in an Erlenmeyer flask. Each mixture was shaken for one hour and then allowed to stand for 24 hours before being evaporated and finally dried in a vacuum oven at 55°C for 12 to 18 hours. The residue was ground with a mortar and pestle and weighed amounts varying from 0.3 to 1.0 gram, depending upon expected heats of immersion, were placed in small glass sample bulbs. These bulbs were blown from pyrex tubing 0.277'' diameter to a final volume of about 7 cm^3.

The bulb containing the sample was brought to temperature equilibrium with the water in a calorimeter, then it was broken and the sample was immersed. The heat evolved was measured with a 100,000 Ω thermistor in a Wheatstone bridge circuit and recorded on a Bristol recorder. Heats of wetting were measured in this manner with a precision of 0.01 calorie per gram of soil. The calorimeter was a modification of the one described by Pierce et al. (1958). The heat generated by breaking an empty sample tube was negligible.

The calorimeter was calibrated before each measurement by putting a measured amount of current at a known constant voltage through the heater for one minute and observing the deflection on the recorder. The resistance of the calibration heater and the voltage were chosen so that the amount of heat they liberated in one minute would produce about the same deflection on the recorder as occurred when the untreated Ca bentonite, which gave the highest heat of wetting, was immersed in the water.

Each calorimeter was placed in a separate water bath and the entire assembly was immersed in a large water bath which was controlled to 0.1°C. Temperature of the water inside the calorimeter would then change less than 0.001° C in each 15-minute period, which was about the time necessary for one calibration and measurement.

RESULTS

The average heats of wetting of three to ten samples of pure calcium bentonite, hydrogen bentonite, and of these bentonites preadsorbed with organic compounds are presented in table 1. The standard error of estimate is between 5 and 10 per cent.

Table 1

Heats of wetting for pure Ca and H bentonite and with five organic compounds preadsorbed

Material Adsorbed	Heats of wetting (cal/gram of clay)	
	Calcium bentonite	Hydrogen bentonite
Pure	12.83	11.22
Isopropylacetate	3.80	1.91
Amylbutyrate	1.48	1.00
Methyl benzoate	0.00	0.06
Ethyl benzoate	0.00	0.00
Methyl ethyl ketone	7.50	11.10

DISCUSSION

The heats of wetting of clay minerals vary with the adsorbed cation (Grim, 1953). The heats of wetting for pure Ca and H bentonite reported here are of the same magnitude as those reported by Slabaugh (1955) for raw bentonite.

All five organic compounds caused a decrease in heat of wetting. The decrease was most evident with the benzoates and least evident with methyl-ethyl ketone. The variation may occur because the adsorption of organic molecules leaves less clean solid clay mineral surface available for water adsorption, and a lower heat of wetting results.

The observed adsorption apparently cannot be fully explained by the proposed bonding between carboxyl groups of the polymer and oxygen of the clay surface (Greenland, 1963; Tensmeyer et al., 1960). In this experiment adsorption also occured with the ketones studied, and these molecules do not have carboxyl groups.

The results can be best explained by assuming that hydrogen bonding occurs between the double-bonded oxygen of the carboxyl group and a hydrogen atom in the clay crystal (Kohl and Taylor, 1961; Tensmeyer et al., 1960). The organic dipolar molecules may be oriented between the basal surfaces of the clay minerals in positions that are parallel to the surfaces (Grim, 1953). Emerson (1957), however, suggested that the orientation of these molecules might be such that the plane of the carbon chain is perpendicular to the (001) plane and not parallel as originally thought. This orientation of the molecules, with carbon chains perpendicular to the adsorbing surface, is supported by Greenland (1963). Our observed heats of wetting are in agreement with this model of orientation. Isopropylacetate has only a single methyl group oriented parallel to the clay surface, while the amyl (C_3H_7) group of amylbutyrate and the phenyl group of methyl- and ethylbenzoate are considerably larger and consequently blanket more than one exchange position. Hence, the heat of wetting of Ca montmorillonite is reduced more with the benzoates adsorbed on the clay surface than with isopropylacetate. The heat of wetting when amylbutyrate is adsorbed on Ca montmorillonite lies between the values for

the acetate- and the benzoate-clay complexes. This agrees with the relative size of the groups parallel to the clay surface. Hendricks (1944) has pointed out the influence of this same „cover-up" effect of organic molecules on the exchange capacity of montmorillonite.

If the carbon chains are directed away from the adsorbing surface, both isopropylacetate and methyl-ethyl ketone would have a single methyl group oriented parallel to the clay surface in the respective organo-montmorillonite complexes. The heats of wetting, therefore, would be expected to be about the same for both complexes. However, the heat of wetting is higher with the ketone adsorbed on the clay surface than with the isopropylacetate. Apparently, the energy of bonding is less for the carbonyl group than for the carboxyl group.

The reason why the heat of wetting of the ketone-H montmorillonite is not significantly different from that of H-montmorillonite is not immediately apparent. The observed difference in energy of bonding of carbonyl-oxygen and carboxyl-oxygen may be a factor, and the presence of the relatively large Al ions that are undoubtedly present in the hydrogen clay system may be partially responsible.

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SUMMARY

Several organic compounds were adsorbed on Wyoming bentonite samples that had been previously saturated with hydrogen or calcium ions. The calorimetric heat of wetting of these samples was determined. All organo-montmorillonite complexes had smaller heats of wetting than the corresponding pure Ca or H montmorillonite. Methyl-ethyl ketone adsorbed on Ca montmorillonite also had smaller heats of wetting. These results mean that adsorption could not be attributed solely to coulombic linkage between a carboxyl group of the compounds and base exchange ions on the surface of the clay. The observed trends in heats of wetting could be explained by hydrogen bonding between the double-bonded oxygens of the carbonyl or carboxyl group and atoms in the clay crystal.

RÉSUMÉ

Plusieurs composés organiques furent adsorbés par des échantillons de bentonite Wyoming qui avaient été saturés au préalable avec des ions d'hydrogène ou de calcium. On a déterminé la chaleur d'humectation calorimétrique de ces échantillons.

Tous les complexes organo-montmorillonitiques ont présenté une chaleur d'humectation inférieure à celle correspondant à la montmorillonite pure de Ca ou de H. La cétone de métyle-éthyle adsorbée par la montmorillonite de Ca a présenté aussi une chaleur d'humectation plus basse. Ces résultats signifient que l'adsorption ne peut pas être attribuée uniquement à la liaison coulombique entre un groupe de carboxyles des composés et les ions des bases échangeables de la surface de l'argile. Les tendances observées à propos de la chaleur d'humectation pourraien-être expliquées par une liaison hydrogénique entre l'oxygène à double liaison du groupe carbot nyle ou carboxyle et les atomes dans le cristal d'argile.

ZUSAMMENFASSUNG

Mehrere organische Verbindungen wurden auf Wyoming Bentonit Proben, welche vorhergehend mit Wasserstoff- oder Kalcium-Ionen gesättigt waren, adsorbiert. Es wurde die kalorimetrische Benetzungswärme dieser Proben bestimmt.

Alle organischen Montmorillonit-Verbindungen wiesen eine niedrigere Benetzungswärme als die entsprechenden reinen Ca- oder H-Montmorillonite auf. Das von den Ca-Montmorilloniten adsorbierte Methyl-Äthyl-Keton hatte ebenfalls eine niedrige Benetzungswärme. Diese Ergebnisse deuten darauf hin, dass die Adsorbtion nicht allein der coulombischen Bindung zwischen einer Carboxylgruppe der Verbindungen und den Basenaustauschionen an der Oberfläche des Tons zuzuschreiben ist. Die beobachteten Richtungen der Benetzungswärme könnten durch die Wasserstoffbindung zwischen den doppelt gebundenen Sauerstoffen der Karbonyl-oder Karboxyl-Gruppe und den Atomen in den Tonkristallen erklärt werden.

DISCUSSION

G. H. BOLT (Netherlands) Judging from the abstract, Dr. Taylor attributes the observed differences in heat of wetting to differences in degree of surface coverage by the organic molecules.

I should like to ask whether Dr. Taylor is of the opinion that it might also be possible that the heat of wetting observed corresponds to the heat of wetting of the unheated sample, minus the heat of desorption of the organic molecules. Does he have any information as to whether the organic molecules remained adsorbed or were possibly desorbed upon wetting?

If no information is available, would not a chemical determination provide an answer to this question?

I. 23

S. A. TAYLOR. Three kinds of bonds occur between organic matter and clay as pointed out in the original paper, namely: hydrogen bonds (1) with a carboxyl group, (2) with a carbonyl group and (3) with the alcohol (OH) group. Infra-red absorption data show that these bonds are of different strengths. The carboxyl bond is quite strong, the carbonyl bond less strong. We are presently studying this problem, but the results are not yet complete. It is my opinion that some of the bonds become very strong once the clay-organic system has been dried. Such bonds have been identified in soil-VAMA (Vinyl acetate maleic Acid co-polymer — Soil-Conditioner) systems that are known to form stable (irreversible) soil structure. Although it is possible that desorption of the sorbed organic molecules takes place it is unlikely that the heat of desorption would not have exceeded the heat of sorption of water in any sample.

A simple qualitative chemical analysis for sorbed organic material would not be sufficient to indicate desorption since there may have been a slight excess of organic material added initially. The number and location of adsorption positions are not known and indeed they are probably different for the different kinds of organic molecules sorbed by the Ca and H saturated minerals. A quantitative analysis may reveal the answer but such determinations have not been made.

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FORMATION OF SOIL AGGREGATES IN CULTIVATED RED EARTH

YAO HSIEN-LIANG, YU TEH-FEN[1]

The formation of soil aggregates in red earths has been previously discussed in literature (Lutz, 1936; Seij, 1962; Kurichichkaya, 1959), but little consideration was given to the changes of soil aggregates in these soils after cultivation. The present paper deals with the composition of cementing materials in various cultivated red earths and the relationship between the cementing materials and the aggregation of soils.

MATERIALS AND METHODS

Soil samples of the surface horizon studied in this paper were collected from Kiangsi in South China. All the soils including eroded red earth, red earth from uncultivated land (0—5 cm), red earth from dry land (0—16 cm), and the arable layer from temporary submerged, submerged and gleyed submerged paddy soils, are derived from quaternary red clay. Except the eroded red earth, all studied soils are of loamy texture. Undisturbed soil samples were collected and air-dried. Water-stable aggregates of 3—1 mm, 1—0.5 mm and < 0.25 mm diameter were separated through wet sieving. The cementing materials were divided into three groups: 1. Clay ($< 1\ \mu$) dispersed with 1 N NaOH and determined with pipette method; 2. Organic cementing materials: a. resinous and bituminous compounds extracted with alcohol-benzene (1 : 1); b. free and weakly combined organic cementing material, extracted with 0.1 N NaOH; c. organic cementing material combined with free sesquioxides extracted with 0.1 N NaOH after removal of R_2O_3 by Tamm solution (pH=3.2); d. organic cementing material combined with clay calculated by the difference after sodium hypobromate treatment. 3. Inorganic cementing materials: a. free iron oxides extracted with Tamm solution; b. iron oxide combined with organic matter, calculated as the difference between the contents of iron oxides with and without organic matter removal. The composition of the cementing materials in the aggregates was analysed. The humic and fulvic acids of the

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organic cementing materials were determined by Tiurin's method. The details of extraction and determination of the cementing materials mentioned above were described by Karrelman (1959). After removal of these materials, microscopic study and particle analysis were carried out.

RESULTS AND DISCUSSION

The degree of soil aggregation (5) is influenced by the contents of cementing materials, especially of organic matter and clay (table 1). The gleyed submerged paddy soil, containing a greater amount of organic matter has a higher degree of aggregation although only a small amount of clay and iron oxide is present.

Table 1

Cementing materials content of the studied soils

soil	Total organic C per cent	Clay (per cent)	Total Fe_2O_3 (per cent)	Free Fe_2O_3 (per cent)	Degree of aggregation
Eroded red earth	0.30	50	4.87	1.22	—
Red earth from uncultivated land (0—5 cm)	1.14	32.8	3.55	0.74	88.4
Red earth from dry land (0—16 cm)	0.66	8.7	2.20	0.52	70.0
Temporary submerged paddy soil (0—10 cm)	0.88	14.8	2.60	0.35	85.0
Submerged paddy soil (0—13 cm)	1.19	16.7	2.59	0.37	79.6
Gleyed submerged paddy soil (0—14 cm)	2.08	12.8	1.95	0.26	96.0

Of course, clay is the essential cementing material in the soil aggregation, but free iron oxide is also significant for the formation of soil aggregates in the red earths. In eroded red earth, only 0.3 per cent organic carbon, 47—50 per cent of clay fraction, and about 1.3—1.5 per cent of free iron oxide are present, and the free iron oxide content in the soil aggregates is with 0.1—0.3 per cent higher than that in the soil itself (table 2). Such results show that the free iron oxide is very active in the aggregation of eroded red earth. In the red earth from an uncultivated land, organic matter plays also a role in soil aggregation in addition to the free iron oxide. In the cultivated red earths, the contents of organic matter content of the soil aggregates (3—0.5 mm) are higher than that of the soil itself. The gleyed submerged paddy soil contains 2.1 per cent organic carbon, and the organic matter content of the soil aggregates (3—0.5 mm) is with 0.1—0.4 per cent higher than that in the soil itself. It is obvious that organic matter is an essential cementing material for the aggregation of cultivated red earths.

Table 2

Composition of the cementing material of the water-stable aggregates in the studied soils

Soil	Diameter of aggregates (mm)	Organic fraction (%)					Inorganic fraction (%)			
		Total C	Resinous and bituminous C	Free & Weakly combined C	C comb. with R_2O_3	C combined with clay	Clay	Total Fe_2O_3	Free Fe_2O_3	Fe_2O_3 comb. with organic matter
Eroded red earth	3—1	0.25	0.05	0.06	0.09	0.04	49.2	4.57	1.29	0.90
	1—0.5	0.27	0.04	0.07	—	—	48.2	4.50	1.31	1.17
	<0.25	0.37	0.03	0.04	0.18	0.05	46.9	4.41	1.50	0.61
Red earth from uncultivated land (0—5 cm)	3—1	1.13	0.09	0.28	0.07	0.51	31.3	3.62	0.79	0.62
	1—0.5	1.05	0.12	0.29	0.12	0.32	30.6	3.59	0.81	0.57
	<0.25	1.05	0.07	0.26	0.09	0.42	27.3	3.34	0.72	0.57
Red earth from dry land (0—16 cm)	3—1	0.70	0.09	0.14	0.15	0.18	7.6	2.57	0.79	0.45
	1—0.5	0.70	0.06	0.12	0.11	0.26	7.2	—	0.81	0.24
	<0.25	0.59	0.03	0.10	0.24	0.12	7.1	2.10	0.71	0.29
Temporary submerged paddy soil (0—10 cm)	3—1	1.20	0.11	0.25	0.10	0.59	13.9	2.80	0.38	0.25
	1—0.5	1.12	0.09	0.26	0.18	0.45	12.8	2.63	0.34	0.35
	<0.25	0.81	0.03	1.19	0.14	0.32	11.5	2.47	0.29	0.41
Submerged paddy soil (0—13 cm)	3—1	1.37	0.13	0.37	0.14	0.55	17.4	2.56	0.41	0.21
	1—0.5	1.30	0.12	0.31	0.18	0.46	16.4	2.61	0.35	0.22
	<0.25	1.07	0.13	0.28	0.21	0.32	15.6	2.27	0.30	0.22
Gleyed submerged paddy soil (0—14 cm)	3—1	2.44	0.15	0.54	0.34	1.06	19.7	2.04	0.29	0.20
	1—0.5	2.18	0.09	0.41	0.27	1.12	19.6	2.02	0.28	0.06
	<0.25	1.70	0.08	0.45	0.21	0.71	16.3	1.86	0.25	0.12

Furthermore, the composition of organic matter in these red earths is quite different. In the eroded red earth and in the red earth from uncultivated land, fulvic acid is predominant, whereas the humic acid content is higher in the cultivated red earth. The humic to fulvic acid ratio of the soil aggregates (3—1 mm), is about 0.1—0.2 in the eroded and uncultivated red earths and 0.5—0.9 in the cultivated red earths (table 3). The organic matter content of the soil aggregates especially the resinous and bituminous compounds, the organic matter combined with clay, and the free and weakly combined organic matter decreases with the decrease of the size of aggregates. In soils with lower organic matter content, the organic matter combined with sesquioxides is concentrated in the small aggregates (< 0.25 mm).

Table 3

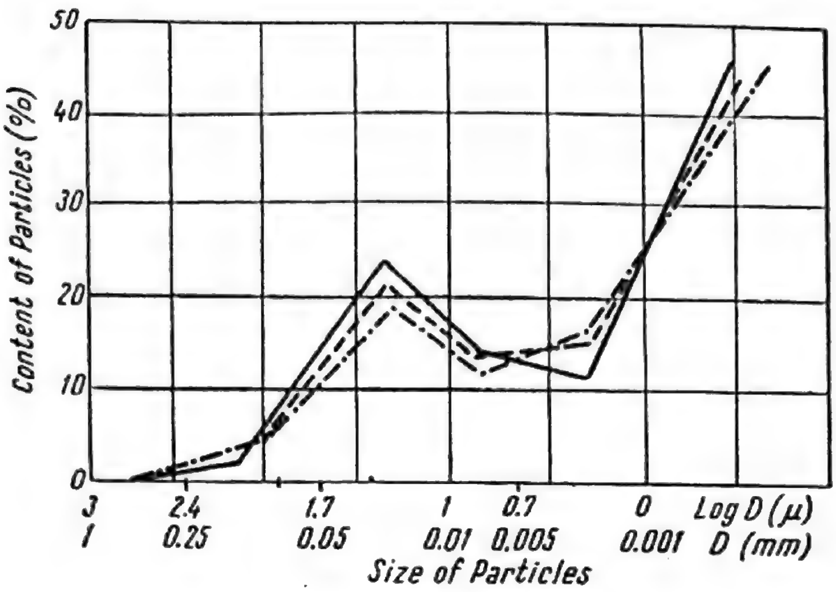
Content of humic and fulvic acid in the cementing material (organic C per cent)

Soil	Eroded red earth	Red earth from uncultivated land	Red earth from dry land	Temporary submerged paddy soil	Submerged paddy	Gleyed submergic paddy soil
Humic acid	0.005	0.056	0.051	0.113	0.164	0.247
Fulvic acid	0.053	0.216	0.088	0.137	0.201	0.291
Humic/fulvic ratio	0.09	0.21	0.58	0.83	0.82	0.85

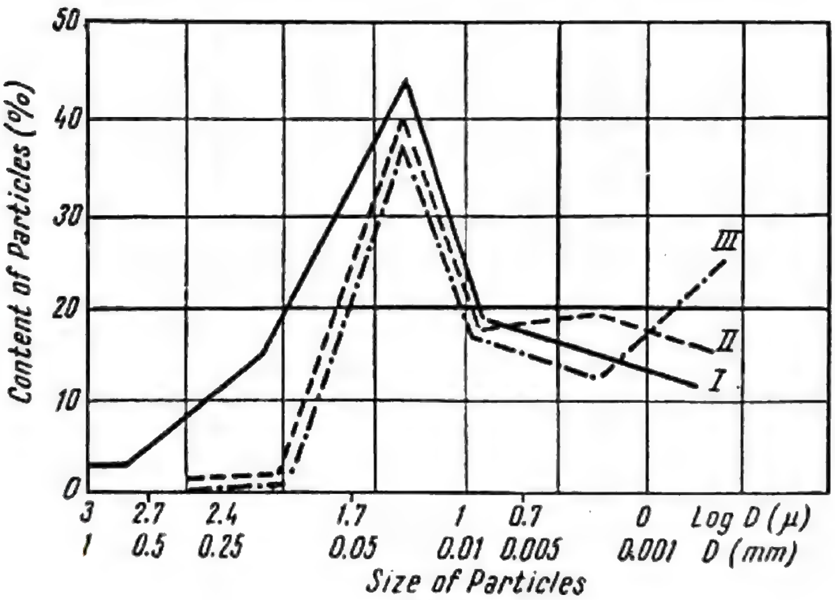
From the above results it is shown that the organic matter plays the chief role in the aggregation of cultivated red earths and that water stable aggregates of large size can be formed by such a cementing process.

The stability and porosity of the soil aggregates and the cementing pattern of the soil particles are affected by the composition of the cementing materials. In the aggregates of eroded red earth, a great part of the clay particles is released after the first 0.1 N NaOH treatment and no more clay fraction is separated through further alkali treatment after removal of free sesquioxides by Tamm solution. On the other hand, in the gleyed submerged paddy soil, organic matter is the essential cementing material and only 50 per cent of the clay fraction is released out after removal of the free and weakly combined cementing materials; and about 70 per cent of the clay fraction is released after further removal of organic cementing materials combined with sesquioxides. The entire clay fraction (100 per cent) can be released only in the case of sodium hypobromate treatment (fig.1)

From microscopic observations, it is found that the particle orientation in the soil aggregates of cultivated red earth is looser and more complicated than that of eroded red earth. It is also shown in table 4 that the porosity of the aggregates is markedly affected by the particle orientation. The aggregate porosity of the gleyed submerged paddy soil is higher than that of other soils.



(a)



(b)

Fig. 1. Size distribution of soil particles within the aggregates after removal of colloidal materials:
a — eroded red earth; *b* — gleyed submerged paddy soil;
I ——— after removal of free and weakly combined organic cementing materials; II — — after removal of free and weakly combined organic cementing materials, and of organic cementing materials combined with R_2O_3; III · — · — after removal of free and weakly combined organic cementing materials, of organic cementing materials combined with R_2O_3, and of organic cementing materials combined with clay.

Table 4

Aggregates porosity in red earths

Soil	Diameter of aggregates (mm)						
	>10	10—7	7—5	5—3	3—2	2—1	1—0.5
Eroded red earth	46.0	41.0	42.8	43.6	43.6	28.7	28.9
Red earth from uncultivated land	50.3	49.8	51.2	48.0	44.0	48.3	20.2
Red earth from dry land	42.2	41.5	44.7	42.6	36.3	—	40.6
Temporary submerged soil	42.2	41.3	41.1	42.5	41.7	34.2	43.2
Submerged paddy soil	45.0	45.1	45.7	45.7	46.5	44.6	45.4
Gleyed submerged paddy soil	50.6	49.5	48.5	49.0	49.0	66.5	57.8

CONCLUSION

The characteristics of the soil aggregates of red earth are quite different. After cultivation, the soil aggregation produced under the clay and free iron oxide cementing action is decreased, and the aggregation by the organic matter cementing action is increased. It was also found that the humic to fulvic acid ratio of the aggregates of cultivated red earth is increased and that the stability and porosity of the aggregates are improved.

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SUMMARY

The present paper deals with the composition of the cementing material in various cultivated red earths and with the relationship between the cementing materials and the formation of the soil aggregates. In the red earth, clay is the essential cementing material of soil aggregates, free iron oxide is also significant for their formation, whereas the organic matter plays the chief role in the soil aggregation of cultivated red earths, especially of the rice paddy soils.

The characteristics of soil aggregates of red earth are quite different. After cultivation, the aggregation produced under the clay and free iron oxide cementing action is decreased and the aggregation due to the organic matter cementing action is increased. It was also found that the humic and fulvic acid ratio of the aggregates of cultivated submerged red earth (paddy soils) is increased and that the stability and porosity of the aggregates are improved.

RÉSUMÉ

La présente communication traite de la composition du matériel de cimentation dans diverses terres rouges cultivées et du rapport entre le matériel de cimentation et la formation d'agrégats de soil. Dans la terre rouge, c'est l'argile qui constitue le matériel de cimentation essentiel; l'oxyde de fer libre est aussi important pour la formation d'agrégats de sol, tandis que la matière organique tient le rôle principal dans l'agrégation des terres rouges cultivées, spécialement dans les sols de rizière submergés.

Les caractéristiques des agrégats de sol de la terre rouge sont bien diverses. Après culture, les agrégats de sol liés par l'argile et l'oxyde de fer libre sont en diminution, tandis que l'agrégation due à la matière organique va augmentant. Il a aussi été établi, que le rapport acides humiques acides fulviques dans les agrégats de terre rouge submergée, cultivée (paddy soils) est accrû et que la stabilité et la porosité des agrégats est améliorée.

ZUSAMMENFASSUNG

Der vorliegende Beitrag befasst sich mit der Zusammensetzung des Zementierungsmaterials in verschiedenen bebauten Roterden und der Beziehung zwischen diesem und der Bildung von Bodenaggregaten. In der Roterde ist Ton das Hauptzementierungsmaterial in der Bodenkrümelbildung, und das freie Eisenoxyd ist gleichfalls wichtig für die Bildung von Bodenaggregaten, wogegen der organische Stoff die hauptsächliche Rolle der Bodenkrümelung bei bebauten Roterden innehat, besonders bei den überschwemmten Reisfeldböden.

Die Merkmale der Roterde-Bodenaggregate sind durchaus verschieden. Nach der Bebauung sind die durch Ton und Eisenoxyd verbundenen Bodenaggregate vermindert und die Krümelung durch organischen Stoff wird vermehrt. Es wurde auch ermittelt, dass das Verhältnis Zwischen Humin- und Fulvosäuren in den Aggregaten von bebauter überschwemmter Roterde (Reisfeldböden) gestiegen, und die Beständigkeit und Porosität der Aggregate verbessert war.

DISCUSSION

E. W. RUSSELL (Kenya). As you will be aware. Tamm's solution extracts both free iron and aluminium hydroxides-oxides, so unfortunately, treating the soil with this reagent cannot distinguish between relative aggregating effect of these two hydrated oxides.

Recent work in Australia undertaken by T. L. Desphande has shown that it is the aluminium and not the iron hydrated oxides which are the active cementing agents.

YAO HSIEN-LIANG. I have no comparing researches concerning the influence of Al_2O_3 and Fe_2O_3 upon cementation of soil particles.

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INFLUENCE OF PARTIAL SODIUM AND MAGNESIUM SATURATION ON THE STRUCTURAL STABILITY OF CLAY SOILS

F. F. R. KOENIGS, R. BRINKMAN

In the Netherlands in the province of Friesland large tracts of clay soil are found, which have a bad repute for their poor physical properties, such as low permeability and moisture conductivity.

They are mostly too dry in summer and too wet in winter, tillage is difficult and the biological activity is low. They are used as permanent grassland. The vernacular name is „Knip" clay.

It is assumed that they have been intermittantly deposited between 400 and 800 A.D. (van Veenenbos and Schuylenborgh, 1951) in brackish slow moving sea-water and that at the time of deposition their calciumcarbonate content was low. This is reflected by a calcium/magnesium ratio of less than 3 and a relatively high percentage of adsorbed sodium (3—10 per cent), both values increasing with depth. It has been a matter of speculation whether the high magnesium content contributes substantially to the bad physical properties of these soils, as suggested by van Schuylenborgh and Veenenbos (1951).

The present investigation was conducted to elucidate this problem.

MATERIAL

Two samples were compared, sample *A* representing the prismatic horizon of a „Knip" clay (24—45 cm) and sample *B* taken at the same depth from a neighbouring marine clay soil. The characteristics of the samples are given in table 1.

The clay fraction consists of quartz and illite, the former mainly found in the fraction 2—0.1 μ the latter in the fraction < 0.1 μ. Sample *A* is lighter than sample B and contains less organic matter and more magnesium and sodium. The high potassium content of sample *B* is probably caused by the large quantities of liquid manure applied to this field due to its close proximity to the farm.

Sample *A* may be regarded as a sodium-magnesium soil and sample *B* as a potassium-calcium soil.

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Table 1

Mechanical and chemical characteristics of the soil samples

Mechanical analysis

Soil sample	per cent separates							
	>50μ	50—20μ	20—10μ	10—5μ	5—2μ	2—0,1 μ	<0,1 μ	texture
A	9	37	10	5	4	23	23	silty clay loam
B	14	24	7	4	7	30	14	silty clay

Chemical analysis

	C. E. C. m.e./100 g soil	per cent C.E.C.				pH (H_2O)	C per cent
		Ca	Mg	Na	K		
A	16,4	59	28	9	4	6,8	0.68
B	21,9	83	0	1,1	16	7.0	1.38

EXPERIMENTS

1. *Stability*

The samples were subjected to the stability test (Koenigs, 1961). In this test the stability of 2 gr of aggregates 2—4 mm. diameter is measured in saturated condition by end over end shaking. The samples were used in the fresh, puddled and dried condition, either with their original composition of the adsorbed cations or after Ca or Mg saturation. Also the influence of the electrolyte concentration of the liquid on the stability was investigated. The Ca or Mg saturation was effected by washing the aggregates in the shaking vessels with a normal solution of the corresponding chlorides followed by several washings with distilled water. Destruction of the aggregates before the test could be avoided by careful manipulation. The puddling was achieved by pressing part of the fresh sample through a sieve of 3,2 mm., without allowing the puddled sample to dry. Although a complete analysis was made of the destruction curves (Koenigs and Schuffelen, 1960). Table 2 only contains the stability indices.

The differences in stability between the two untreated moist samples are striking. From the complete analysis of the destruction curves it could be deduced that 36 per cent of soil *A* and only 8 per cent of soil *B* disperse spontaneously. If 0.002 N solution of Mg- or Ca- sulfates are used as medium instead of distilled water, the stability index of soil *A* is increased eightfold, that of soil *B* less than doubled. The large increase of the stability index of soil *A* is caused by two factors, viz. the exchange of the monovalent ions on the adsorption

complex against the divalent ions from the solution, and the rise of the concentration of the surrounding solution as well. With the aid of the exchange constants (Lagerwerff and Bolt, 1959; van Schouwenburg and Schuffelen, 1963) and the data of table 1 it could be calculated that the percentage of adsorbed sodium decreased after equilibration with the first 60 ml of 0.002 N solution from 9 to. 0.8. per cent of the C.E.C. As the exchange of Na is thus virtually complete before the start of the experiment, only the influence of the electrolyte concentration on the stability of Ca or Mg clay is investigated in this series. From the large increase in stability of soil A, which is much larger than the expected effect of concentration increase alone, and from the stability of the moist calcium saturated sample in distilled water it can be deduced that the increase of the stability index is due to cation exchange.

Table 2

Stability indices (x 1000) of samples A, B and Winsum soil (Koenigs, 1961)

Condition at start	Chemical treatment before test	Liquid	Stability index		Index ratio Mg/Ca	
			A	*B*	*A*	*B*
field condition	none	water	16	364		—
do	do	0.0022 N $MgSO_4$	120	—	0.82	—
do	do	0.0088 —	193	—	0.90	—
do	do	0.035 —	252	—	0.81	—
do	Ca saturated	water —	135	—	—	—
do	none	0.002 N $CaSO_4$	147	590	—	—
do	none	0.008 —	215	770	—	—
do	none	0.032	311	1 200	—	—
puddled	none	water —	1.5	8	—	—
do	Mg saturated	do —	53	131	0.67	0.83
do	Ca saturated	do —	79	159	—	—
dried	none	do —	112	468	—	—
do	Mg saturated	do —	264	604	0.91	0.86
do	Ca saturated	do —	290	704		
artificial aggregates*	Mg saturated	do —	340	624	0.81	0.70
	Ca saturated	do —	416	892		
do**, oxydized	Mg saturated	do —	15	54	0.52	0.77
	Ca saturated	do —	29	70		
	do, slowly moistened	do —	—	420		
Winsum soil			pH 7	pH8.2	pH 7	pH8.2
air dried, immersed	Mg saturated	0.0002 N $MgCl_2$	1 200	835	0.78	0.54
	do	0.002	1 350	1 030	0.73	0.56
	do	0.02 —	1 670	1 440	0.68	0.59
air dried, slowly wetted	Ca saturated	0.0002 N $CaCl_2$		1 550		
	do	0.002 —		1 850		
	do	0.02 —		2 460		

* Suspensed, satu ated, aceton washed and dried.
** Suspended, H_2O_2 treated, saturated, aceton washed and dried.

The influence of magnesium on the increase of stability is comparable to that of calcium. When the stability of sample *A* is analysed after it had been puddled by pressing through a sieve, it is found to be very small. About 50 per cent of the soil disperses spontaneously in water. The reason of the decrease in stability is that the humus bonds, tying together the clay and sand particles, are broken and that by the more parallel arrangement between clay plates the edge to plate attraction is decreased (Koenigs, 1963). The stability was increased by saturating the puddled soil with calcium or magnesium and no spontaneous peptisation was observed after repeated washing with distilled water. By an elimination of sodium and a saturation with divalent ions the swelling pressure is decreased, the edge to plate attraction increased and the humus bonds are strengthened.

A drying at 105°C markedly improves the stability of these subsoils and the differences between the natural and the Mg- or Ca- saturated soil samples become less. Whether the increased Madelung attraction, caused by the smaller distances between the clay crystals is to be regarded as the main cause, or the irreversible drying of organic or inorganic colloids, it can not be ascertained. The period of soaking before the test amounted to one week; therefore it may be assumed that the rehydration was complete.

Both tests with artificial aggregates show that the stability of this soil is enormously decreased by the removal of organic matter. The cause of this decrease is probably the enhanced susceptibility for slaking by entrapped air as will be shown later.

In the case of *B* the influence of exchange and increase of salt concentration on the stability of the moist and natural sample is much lower than with *A*. This is to be expected, as the stability of an aggregated clay soil fully saturated with potassium is similar to that of a calcium soil and is only slightly dependent on salt concentration (Koenigs, 1961).

After puddling, however, potassium soils disperse spontaneously, because in these soils the Madelung attraction has a very small range. The high percentage of potassium saturation of sample *B* is probably responsible for the very low stability after puddling as compared with the puddled soil completely saturated with either Mg or Ca.

By drying, the stability of the soil is increased again but less markedly than that of sample *A*; the factor amounts to 1.6 instead of 7.5.

The stability of the artificial aggregates is only slightly higher than that of the natural ones; it decreases to one twelfth of its value when the organic matter is removed from the soil. As all dried soils were introduced into the shaking bottles without a preceding slow saturation with water, one of the causes of the low stability might have been the air entrapped inside the aggregates, thus providing for an additional expansive force. Therefore the analysis was repeated with the calcium saturated aggregates free of organic matter after a preceding wetting against a suction of 20 cm water. By slow wetting the stability was increased six fold and its value amounted to half of that of the aggregates containing organic matter. Although no experiment was done with slowly wetted aggregates containing organic matter and a strict comparison

can not be made. Previous experiments (Koenigs, 1961) have shown that with clay soils of the same type and containing organic matter the influence of a sudden wetting is negligible.

2. *Permeability*

To investigate whether the sedimentation in brackish water without precipitated $CaCO_3$ and a formation of FeS, may have been the cause of the low permeability of the „Knip" clay, the permeability of a soil suspension in sea-water was determined after partial desorption. The procedure was as follows: a known volume of the 5 per cent suspension in sea-water of sample A was brought on a Göttingen membrane in porcelain Szigmondy filters (Ø 6 cm). The part of the funnel underneath the membrane was previously filled with water, as was also the rubber tube connected with the outlet. The outlet of the rubber tube was at a level of 1 m below the membrane. After equilibration of the suspension with this suction the permeability was determined with a constant head. From the moisture content of the suspension on the membrane, the thickness of the filter cake could be calculated and with the aid of the previously determined apparatus constants, also its permeability. After the determination of the permeability for sea-water, either water or other solutions were percolated and the permeability determined in the same way. The results are given in table 3.

The permeability of the sea-water sediment, found in these experiments, is of the same order of magnitude as that found in field experiments in the

Table 3

Permeability of suspensions desorbed at pF 2, gradient 1m/m

Material	Percolation sequence	Permeability 10^{-2}cm/day	Percolation sequence	Permeability 10^{-2}cm/day
Sample *A*	sea-water	4.9	sea-water-water	0.09
	sea-water-gypsum sol.	4.8	sea-water-gypsum sol.	4.3
			water	2.8
	sea-water-$MgSO_4$ 32 me/l	5.5	sea-water-$MgSO_4$, 32 me/l	3.9
			water	1.8
do + 10 per cent gypsum	sea-water	7.0	sea-water-	8
			water	6.8
do + 10 per cent $CaCO_3$	sea-water	5.8	sea-water-	3.3
			water	0.48
			seawater CO_2 sat. water (1 atm)	5.8
			sea-water-CO_2 sat. water (I atm.)	4.7
			water	3.3
Org. matter removed	sea-water-water	0.11	sea-water-water gypsum sol.	0.10

Netherlands (Zuur, unpublished data). If after sea-water the soil is percolated with a saturated gypsum, or equivalent $MgSO_4$ solution, the permeability is nearly maintained. Even a subsequent percolation with fresh water only lowers the permeability with a factor of about two. Apparently the concentration of the Mg- and Ca- solutions is sufficient to prevent deflocculation during the time when the soil is still partly saturated with sodium. After the sodium has been removed by exchange a subsequent leaching with distilled water does not seem to diminish the edge to plate attraction to such a degree that the structure would collapse. If, however, the soil is percolated with distilled water directly after the percolation with sea-water, deflocculation and swelling take place and the permeability drops by a factor 50. Gypsum when mixed through the soil dissolves at a rate which is high enough to maintain a sufficient salt concentration. If calciumcarbonate is used then the permeability is decreased substantially when percolation with sea-water is followed by one with distilled water being in equilibrium with the normal carbondioxide pressure of the air. Only when the latter is raised the calciumcarbonate dissolves quickly enough to prevent deflocculation. Subsequent lowering of the carbondioxide tension does not markedly influence the permeability because the sodium has already been displaced. The last series shows that a substitution of sodium ions by calcium does not help to restore the permeability once the structure has collapsed; this was also found by Wiklander and Hallgren (1944).

CONCLUSION

From these stability experiments it may be concluded that the low stability of sample *A* is not caused by the 28 per cent exchangeable magnesium but originates both from the 9 per cent exchangeable sodium and the low content of organic matter. The latter is shown by the fact that even the dried natural calcium-saturated aggregates of sample *A* have only a stability index 0.29 against 0.70 in the case of sample *B*.

The second conclusion is that the magnesium saturated samples behave very much like the calcium saturated soils, although their stability is consistently somewhat lower (factor 0.8). When working with granules prepared from the clay fraction of similar composition and free of organic matter the first author could not detect any difference in stability between the calcium and magnesium saturation at pH = 8. Only with the granules of Winsum clay soil a difference in stability between Ca- and Mg- soils and also an influence of pH were detected. With a basin clay soil (Rhine sediment), however, no such influence was found. It is doubtfull whether the conversion of $Mg^{\cdot\cdot}$ to $Mg(OH)^{\cdot}$ which is brought forward as an explanation by van Schuylenborgh and Veenenbos (1951) could play a role.

Stock and Davies (1948) determined the second dissociation constant of $Mg(OH)_2$ as 0.0026. This means that at pH 10 where the OH' concentration is 10^{-4} the ratio $Mg^{\cdot\cdot}/Mg(OH)^{\cdot}$ is 26; $\left(2.6 \cdot 10^{-3} = \frac{Mg^{\cdot\cdot} \times OH')}{Mg(OH)^{\cdot}}\right)$.

There seems to be no reason for a lowering of this dissociation constant in the immediate neighbourhood of the negatively charged clay surface.

For the conversion of sea-water sediments into normal soils (the transition of a Bingham liquid into a solid) the cooperation of several processes is required; desalinization, oxydation leading to gypsum formation (SO_4^{2-} formation by oxydation of FeS, interacting with $CaCO_3$), exchange of the adsorbed sodium and part of the magnesium by calcium, dehydration of the sediment causing largely irreversible shrinkage. The degree of irreversibility is closely correlated with the saturated stability of the aggregates formed by shrinkage. In case insufficient gypsum is present, lack of $CaCO_3$ and FeS, the replacement of Na and Mg is not complete. As the saturated stability of partly sodium saturated soils is low (Quirk and Schofield, 1955) at the salt concentration occurring in soils, macropores can not exist in the saturated stage and a dense structure of these soils is the result. Though the stability of the aggregates may be largely improved by replacing the Na by Ca, this replacement itself will not improve the dense structure. The macropores must be created by deep tillage and/or biological activity. Only little additional improvement of the aggregate stability is to be expected if also the adsorbed Mg is replaced by Ca.

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SUMMARY

It has been established that the physical behaviour of magnesium saturated soils does not differ significantly from that of calcium soils. The high percentage of magnesium in soils formed from brackish sea-water deposits is therefore not the cause of their bad structure but a relict of the adverse conditions during the past desalinization period.

.ESUMÉ

Il a été établi, que le caractère physique des sols saturés en magnesium ne diffère guère de celui des sols saturés en calcium.

Le pourcentage élevé de magnesium observé dans les sols formés des dépôts d'eau saumâtre n'est donc pas la cause directe de leur mauvaise structure, mais un relict des conditions adverses datant de la période de désalinization.

ZUSAMMENFASSUNG

Es wurde erwiesen, dass die physikalischen Eigenschaften der mit Magnesium gesättigten Böden sich nur in geringem Masse von denen der Calciumböden unterscheiden. Der hohe Gehalt an Magnesium der Brackwassermarschen ist also nicht als die Ursache ihrer schlechten Struktur, sondern als ein Relikt der ungünstigen Umstände während der Entsalzungsperiode anzusehen.

DISCUSSION

W. H. VAN DER MOLEN (The Netherlands). Did soil *B* contain $CaCO_3$? Its presence is suggested by the behaviour of this soil if suspended in distilled water.

F. F. R. KOENIGS. Some $CaCO_3$ is present in soil *B*, but its influence is small. This is shown by the fact that the destruction curve of the puddled soil *B* in its natural composition is much steeper than the same after Ca-saturation.

th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

THE EFFECT OF POTASSIUM FERTILIZERS ON SOIL STRUCTURE

P. A. VLASIUK [1]

For a long time opinions were predominant that the application of potassium fertilizers caused a structure dispersion in soils and that, consequently, they can be applied only under perennial grass in a crop rotation Williams, 1951). Such views proved to be erroneous.

Experimental researches carried out by the author with A. L. Pechura on ordinary irrigated chernozems with signs of solonetzisation (1952—1964) have shown that the application of different forms of potassium fertilizers (in dozes from 30—45 to 60 kg/ha of K_2O) did not cause any structure dispersion.

Data of table 1 confirm that the number of agronomically valuable aggregates did not diminish under the influence of potassium fertilizers in any variant of the experiment, whereas yields of winter wheat, corn, sugar beet and potatoes increased.

By the application of potassium sulphate and chloride, or of sulphate of potash-magnesia, and in a number of cases even of kainite, to sugar beet, winter wheat and potatoes, a coagulation of colloidal particles has been recorded and an increase in the number of water-stable structural aggregates. Under the influence of potassium sulphate and potassium chloride or their mixture (50 per cent each) there has been an increase in soil aggregate (table 2)

Table 1

Effect of potassium fertilizers applied to sugar beet on the aggregate -size distribution of an ordinary chernozems (in %)

Experiment scheme	Size of aggregates (in mm) — over:					
	5	3	2	1	0,5	0,25
No fertilizers	2.95	2.44	1.69	3.84	6.86	33.62
Nitrogen and phosphorus	1.49	2.49	2.02	3.06	7.34	20.86
Ditto + potassium chloride	6.61	3.94	3.27	6.23	8.21	11.18
Ditto + potassium sulphate and potassium chloride (50% each)	4.65	3.85	2.84	8.28	10.14	11.12
Ditto +potassium sulphate	10.33	5.74	2.99	7.55	14.06	15.61
Ditto + sulphate of potash-magnesia	11.79	3.15	2.50	7.10	10.47	9.67
Ditto + kainite	12.35	5.45	2.64	5.83	9.90	14.72

[1] The Institute of Plant Physiology, Kiev, U.S.S.R.

Table 2

Effect of potassium fertilizers on yields, amount of water-stable aggregates and soil dispersity

Experiment scheme	Depth of soil horizons cm	Sugar beet						Winter wheat				
		1952	1953		1954			1952		1953		
		Dispersity per cent 22.V.	Particles >0.25 mm 25.IX.	Yield in c/ha	Dispersity per cent 22.V.	Particles >0.25 mm per cent 25.IX.	Yield in c/ha	Dispersity per cent 3.VI.	Yield in c/ha	Dispersity per cent 16.7.	Particles >0.25 mm 16.7.	Yield in c/ha
Nitrogen and phosphorus	0—25	0.264	68.1	289	0.160	48.9	300	0.128	26.7	0.204	48.2	22.4
	25—50	0.224	—	—	0.298	—	—	0.208	—	0.208	—	—
Ditto + potassium sulphate	0—25	0.264	71.9	330	1.164	51.3	345	0.134	28.8	0.160	52.9	24.5
	25—50	0.272	—	—	0.336	—	—	0.120	—	0.240	—	—
Ditto + potassium chloride	0—25	0.092	71.4	314	0.136	54.5	333	0.144	30.2	0.144	50.7	25.2
	25—50	0.252	—	—	0.088	—	—	0.136	—	0.232	—	—
Ditto + potassium sulphate and potassium chloride (50 per cent each)	0—25	0.124	71.9	325	0.160	50.2	344	0.136	27.8	0.224	49.9	25.8
	25—50	0.216	—	—	0.210	—	—	0.128	—	0.228	—	—
Ditto + kainite	0—25	0.260	63.7	305	0.134	47.0	320	0.160	29.0	0.208	58.4	24.1
	25—50	0.224	—	—	0.272	—	—	0.264	—	0.184	—	—
Ditto + sulphate of potash-magnesia	0—25	0.296	67.0	324	0.180	—	389	0.152	—	0.176	58.5	25.0
	25—50	0.200	—	—	0.312	—	—	0,144	—	0.200	—	—

under sugar beet and winter wheat, as well as in their yields. A decrease in aggregate content has been recorded only after the application of kainite to sugar beet. Consequently, no soil dispersion that would be reflected in its structure has been observed.

Data of table 3 show that under row crops — sugar beet and potatoes—the application of potassium sulphate resulted in an obvious coagulation of soil colloids and an increase in the content of structural aggregates. This was especially encouraged by the application of potassium chloride, sulphate of potash-magnesia and kainite. This completely eliminates soil dispersity as an effect of potassium fertilizers and raises the question of their wide use.

Table 3

Effect of potassium fertilizers on the dispersity and structural aggregates of an ordinary light loamy chernozem (1953)

Experiment scheme	Depth of soil horizons in cm	Sugar beet		Potatoes
		Dispersity per cent 26.V.	Particles >0.25 mm (in per cent) 26. V.	Particles >0.25 mm (in per cent) 26. V.
Nitrogen and phosphorus	0—25	0.280	40.0	49.8
	25—50	0.376	—	—
Ditto + potassium chloride	0—25	0.240	45.3	—
	25—50	0.232	—	—
Dito + potassium sulphate	0—25	0.168	40.0	53.4
	25—50	0.208	—	—
Ditto + potassium sulphate and potassium chloride (50 per cent each)	0—25	0.288	42.4	53.7
	25—50	0.280	—	—
Ditto + kainite	0—25	0.284	44.8	—
	25—50	0.248	—	—
Ditto + sulphate of potash-magnesia	0—25	0.280	44.2	57.9
	25—50	0.208	—	—

It should be remembered that there is a complicated interaction between the cation part of potassium fertilizers and soil colloids. From the point of view of modern data the adsorbing soil complex plays an exceptionally important role in soil aggregation, in sofar as its organo-mineral, organic and mineral colloids are in intimate interrelation with the soil solution and with the larger particles forming hydrosols, hydrogels and aggregates.

Exchange and adsorption reactions take place only with atoms, molecules and ions, which are on the surface of colloid particles. They promote a more intense adsorption and coagulation of minute particles into larger aggregates. Thus, growth, development and productivity of crops depend upon a whole complex of factors, including the capacity and nature of the adsorbing complex (Gedroitz, 1932) the composition and structure of the soil, and, the potassium status of the soil. This has been very clearly confirmed by the yields of sugar beet, winter wheat and potatoes, as affected by various potassium fertilizers.

After the application of X-ray and chromatography methods of analysing fine colloidal fractions, DTA, electronography, infra-red spectroscopy, labelled atoms and electron microscopy, our concepts on the soil-adsorbing complex have essentially changed. At present we have a vast amount of data on the compounds, which are a part of the colloids in different soil types. This caused radical changes in our ideas on colloids, the adsorbing complex, physical properties and soil fertility (Vlassiuk and Sedletzky, 1960, Prianishnikov, 1952).

Together with Sedletzky we succeeded to show that soil colloids in an electronic microscope (x 10,000—40,000) are mostly finely cristalline, the amorphous part being insignifiant. While previously it was thought that soil colloidal particles have a globular shape, it has been proved that such a shape has mostly amorphous compounds, while most of the colloids are peculiar and varied in form. We find here hexahedral laminae in the form of hexagons, laminae with badly eroded edges, separate tubules, splinters, rods, needles and even filiform shapes. All this depends upon the minerals of the colloidal part. Such minerals amount now to over 100 species and varieties including montmorillonite, kaolinite, illite, nontronite, halloysite and many others.

Among organic colloids we have established high-molecular aromatic oxicarboxilic acids, humic and fulvic acids, crystals of humic acid of a disc-like shape, various fractions of active humus etc. The organic part of the soil interacts with the minerals part, this being substantially encouraged by microflora, microfauna and, especially, by the application of fertilizers and tillage.

On the basis of the above mentioned facts it is possible to come to the following conclusions:

1. Present successes in the study of the composition of colloid minerals in the soil and of the humus permit a more rational use of soils and fertilizers in agriculture.

2. Our researches carried out on irrigated lands, indicate that potassium fertilizers do not disperse the soil.

3. Different forms of potassium fertilizers have a positive effect on potassium nutrition of plants, on structure and on physical properties of ordinary chernozems (with traces of solonetization). Sugar beet, winter wheat and potatoes considerably increase their yields and quality.

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SUMMARY

On the basis of many years' investigations, the author concludes that present achievements in the study of colloïdal minerals and humus allow a more complete development of soil and fertilizer use for agricultural purposes.

The experimental researches carried out by the author in conditions of irrigation proved that potassium fertilizers do not disperse soil structure, that some of them increase significantly the yields and quality of sugar-beet, spring wheat and potatoes and enhance the potassium nutrition of plants as well as the physical properties of ordinary chernozems with traces of solonetzisation from the Ucrainian steppe regions.

RÉSUMÉ

Se fondant sur des recherches de plusieurs années, l'auteur arrive à la conclusion que les progrès actuels dans l'étude de la composition des colloïdes du sol et de l'humus rend possible une mise en valeur plus complète des sols et des engrais en agriculture.

Les recherches expérimentales effectuées par l'auteur dans des conditions d'irrigation ont prouvé que les engrais minéraux à potassium ne font pas disperser la structure du sol et que même ils font augmenter sensiblement les récoltes de betterave sucrière, de blé d'été et de pommes de terre, ils améliorent la qualité des produits agricoles, les conditions de nutrition potassique des plantes ainsi que la composition et les propriétés physiques des chernozems ordinaires à traces d'alcalinité des régions de steppe de l'Ukraine.

ZUSAMMENFASSUNG

Auf Grund mehrjäriger Untersuchungen gelangt der Verfasser zur Schlussfolgerung, dass die heutigen Erkenntnisse über die Zusammensetzung der mineralischen Bodenkolloïde und des Humus es ermöglichen, in der Landwirtschaft Böden und Düngemittel vollständiger zu verwerten.

Die vom Verfasser unter Bewässerungsbedingungen durchgeführten Versuchsstudien haben gezeigt, dass die Kalidüngemittel die Bodenstruktur nicht dispergieren, wobei einzelne ihrer Formen die Zuckerrüben-, Sommerweizen und Kartoffelernten merklich erhöhen, die Qualität der landwirtschaftlichen Erzeugnisse, die Kaliernährung der Pflanzen und die Beschaffenheit und physikalischen Eigenschaften der gewöhnlichen Tschernoseme aus der Steppenzone der Ukraine, die Spuren von Alkalinität aufweisen, verbessern.

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I. 27

DIE WIRKUNG VON POLYMEREN AUF DIE STRUKTUR EINIGER BÖDEN BULGARIENS

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In vielen Ländern wird in den letzten Jahren die Wirkung untersucht, welche Polymere auf die Bodenstruktur ausüben. Trotzdem ist eine Reihe von Fragen noch nicht genügend geklärt, wobei zu bedenken ist, dass die Böden Bulgariens eine Reihe von spezifischen Besonderheiten (Antipoff-Karataeff, 1960) aufweisen, welche durch die physikalisch-geographischen Verhältnisse bedingt werden. Es sind daher bei uns Unterschiede in der Wirkung der Polymere zu erwarten.

In der vorliegenden Mitteilung werden die Ergebnisse der Untersuchungen über die Wirkung folgender, im Ausland erzeugter Polymere angeführt: „Verdickung AN" (DDR), „Solakrol" (Ungarische VR) und „Soiluck" (Japan). Die Untersuchungen bezogen sich auf grauen Waldboden, ausgelaugten zimtfarbigen Waldboden, Solonetz-Solontschak und ausgelaugten Tschernosem-Smolnitza.

Die untersuchten Böden lassen sich kurz folgendermassen charakterisieren: der graue und der zimtfarbige Waldboden sind schwere Lehmböden (46—51% Korngrösse < 0,01 mm und 28—30% < 0,001 mm). Der Humusgehalt ist niedrig (1,6—2,3%). Sowohl bei dem grauen als auch bei dem zimtfarbigen Waldboden handelt es sich um altes Ackerland, weshalb die Bodenstruktur stark zerstört ist (78—82% Korngrösse < 0,25 mm). Der Solontschak-Solonetzboden ist ein mittelschwerer sandiger Lehm, dessen Humusgehalt sehr niedrig ist. Infolge des hohen Gehaltes an austauschbarem Natrium besitzt dieser Boden keine wasserfeste Makrostruktur. Sein Gefüge ist sehr dicht, die Wasserdurchlässigkeit ist praktisch gleich Null. Eine besondere Stellung kommt unter genannten Böden dem Tschernosem-Smolnitza zu. Charakteristisch für diesen Boden ist der Umstand, dass seine Krümel gegen Zerstäubung sehr widerstandsfähig sind (Galewa und Demjanoff, 1956). Obwohl es sich um Boden von altem Ackerland handelt, enthält er daher einen hohen Anteil an wasserfesten Krümel von der Grösse 1—0,25 mm (73%). Infolge des tonigen Charakters (71% der Teilchen < 0,01 mm und 55% < 0,001 mm) und des Gehaltes an Tonmineralien der Montmorillonitgruppe, weist dieser Boden jedoch ungünstige physika-

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lisch-mechanische Eigenschaften auf. Wir haben den Tschernosem-Smolnitza in unsere Untersuchungen einbezogen, um festzustellen, ob die Polymere zur Bildung von wasserfesten Krümel > 1 mm in diesem Boden beitragen können.

Zur Bestimmung der Wasserfestigkeit der Krümel wurde eine Modifikation der Savinovsmethode für Krümelanalyse (Werschinin und Revut, 1957) benutzt. Die Probe wurde vor dem nassen Absieben im Laufe von einer Stunde im Wasser gehalten.

Das Polymer „Verdickung AN" stellt ein Na-NH_4-Polyakrilat dar, „Solakrol" ist ein Na-Polyakrilat und „Soiluck" ist ein azetylierter (etwa 90, mol. %) Polyvinylalkohol.

Nach Katschinski (1962) sind die Polymere in schwachen Konzentrationen nicht imstande, eine befriedigende strukturbildende Wirkung auszuüben. In bezug auf „Verdickung AN" nimmt er an, dass es bei den von ihm untersuchten Böden erforderlich ist, eine Konzentration von 0,2% anzuwenden. Bezüglich desselben Polymers, empfiehlt Bergmann (1955) unter den Bodenverhältnissen der DDR die Anwendung einer Konzentration von 0,01—0,05%. Die optimale Konzentration variiert also je nach den Böden in ziemlich weiten Grenzen. In unseren Versuchen haben wir die Wirkung folgender Konzentrationen geprüft: 0,005, 0,02, 0,05, 0,1, 0,2 und 0,5 %.

Bei unseren Laboratoriumsuntersuchungen benutzten wir zerriebene Böden mit Korngrösse < 0,25 mm, um festzustellen ob die Polymer imstande sind, die Bodenstruktur nach Wölligers mechanischer Zerstörung der natürlichen Makrokrümel des Bodens, wiederherzustellen. Bei diesen Versuchen konnte man natürlich auch eine strukturbildende Wirkung unter dem Einfluss der im Boden vorhandenen organischen und mineralischen Kolloide (Wilenski, 1945, Werschinin, 1953, u.a.) erwarten. Um ein richtiges Urteil über die Wirkung der Polymere zu gewinnen, haben wir in unser Versuchsschema auch eine Variante mit Krümelbildung der zerriebenen Böden durch Wasseranfeuchtung eingeschlossen.

In der Literatur wird gewöhnlich die Wirkung der künstlichen Bodenverbesserungsmittel unter Zugrundelegung des Anteils der Krümel > 0,25 mm beurteilt. Bei den Böden, welche eine schwerere mechanische Zusammensetzung besitzen, ist es unseres Erachtens von grosser Bedeutung ob diese summare Fraktion vornehmlich aus kleinkörnigen Krümel 1—0,25 mm besteht oder aber auch Krümel > 1 mm enthält, weshalb wir die Daten in folgende Fraktionen zusammengefasst haben: > 1, 1—0,25, < 0,25 und Summa > 0,25 mm.

Aus der Tabelle 1 ersieht man, dass das Zusammenballen der Teilchen zu Krümel durch Anfeuchtung lediglich mit Wasser bei den Tschernosem-Smolnitza die Bildung einer grossen Menge wasserfester Krümel bedingt, welche, wie bei dem Ausgangsboden (vor dem Zerreiben), von der Grösse 1—0,25 mm sind. Bei dem grauen und dem zimtfarbigen Waldboden wird gleichfalls eine gewisse Menge Krümel der genannten Fraktion gebildet, doch ist sie bedeutend geringer (8% gegen 59% bei dem Tschernosem-Smolnitza). Dadurch wird das auch von anderen Verfassern (Behar, 1959) festge-

stellte Vermögen des Tschernosem-Smolnitzabodens bestätigt: bei ihm werden unter dem Einfluss der Anfeuchtung und Trockung die mechanisch zerstörten Krümel wiederhergestellt. Bei dem Solontschak-Solonetzboden hat die Anfeuchtung keine Wiederherstellung der Struktur bedingt, was auch zu erwarten war.

Bei den Versuchen zur Neustrukturbildung bei zerriebenen Böden durch Polymere konnte festgestellt werden, dass die schwächste Konzentration 0,005%, die Bildung vornehmlich von Krümel der kleinkörnigen Fraktion 1—0,25 mm bedingt. Am grössten ist die Wirkung bei dem grauen und dem zimtfarbigen Waldboden, bei welchen der Strukturzustand der Ausgangsproben wiederhergestellt wird. Bei dem Tschernosem-Smolnitzaboden ist die Wirkung sowohl der Konzentration 0,005% als auch der höheren Konzentration 0,02% nicht nennenswert. Im Gegensatz zu diesem Boden wird bei dem grauen und dem zimtfarbigen Waldboden unter dem Einfluss der Konzentration 0,02% der Gehalt an neugebildeten Krümel verdoppelt. Wie dies auch bei der schwächeren Konzentration der Fall ist, gehören sie zu der kleinkörnigen Fraktion. Ausserdem sei darauf hingewiesen, dass die Konzentration 0,02% eine deutliche Wirkung auch bei Solontschak-Solonetz ausübt, was dem nichtaustauschbaren Charakter der gegenseitigen Wirkung der Polymer mit dem Boden entspricht.

Aus der Tabelle 1 ersieht man gleichfalls, dass bei weiterer Zunahme der Konzentration bei allen Böden, abgesehen von Solontschak-Solonetz, die Wirkung der Polymer im Sinne der Neubildung von Krümel allmählich abnimmt. Es beginnt jedoch die Bildung von Krümel > 1 mm. Auch hier also, d.h. nicht nur bei den schwachen Konzentration ist die Wirkung bei dem grauen und dem zimtfarbigen Waldboden am grössten. Es fällt überhaupt auf, dass bei dem Tschernosem-Smolnitza das Vorhandensein grösser Krümelmengen der kleinkörnigen Fraktion (1—0,25 mm) zur Erhöhung der Wirkung der Polymere und zur Bildung von wasserfesten Krümel > 1 mm nicht beiträgt. Es ist dies wahrscheinlich auf die bedeutende Quellung (durch die Beteiligung des Montmorillonits an der Zusammensetzung des Tons bedingt), zurückzuführen, wodurch eine Schwächung der Makrokrümelbindungen zustandekommt.

Bei Behandlung von Böden mit natürlicher Strukturzusammensetzung ist die Wirkung der Polymere bedeutend stärker. Aus der Tabelle 2 ersieht man, dass die Konzentration 0,02% bei dem grauen und dem zimtfarbigen Waldboden die Bildung von 58—79% wasserfester Krümel > 0,25 mm bedingt, was eine Verdreifachung, bzw. Vervierfachung im Vergleich zu den Ausgangsböden bedeutet. Bei dem Solontschak-Solonetz haben wir eine anderthalbfache bis zweifache Zunahme. Infolge des hohen Gehaltes an Krümel dieser Grösse im natürlichem Boden ist die Wirkung der Polymere bei dem Tschernosem-Smolnitza am geringsten (85—93% Krümel 0,25 mm bzw. 75%).

Man sieht also, dass die Wirkung der Konzentration 0,02% zur Erzielung einer grossen Krümelmenge > 0,25 mm völlig ausreichend ist. Diese Konzentration ist jedoch nicht wirksam, wenn man die Bildung wasserfester Krümel > 1 mm anstrebt. Viel günstiger in dieser Hinsicht ist die Kon-

Tabelle 1

Gehalt an wasserfesten Krümel bei Behandlung von zerriebenen Böden mit Polymeren und Wasser

Zähler > 0,25 mm grosse Krümel; Nenner > 1 mm grosse Krümel

Bodentyp	Boden mit natürlicher Strukturzusammensetzung, nicht behandelt	Aqua	Polymere bzw. Konzentration in %													
			Verdickung AN					Solakrol					Soiluck			
			0,005	0,02	0,05	0,1	0,5	0,005	0,02	0,05	0,1	0,5	0,005	0,02	0,05	0,1
Ausgelaugter zimtfarbiger Waldboden	18/5	8/0	19/0	48/0	59/3	64/33	76/59	22/0	38/0	52/10	62/34	67/49	23/1	39/0	44/33	58/42
Grauer Waldboden	22/2	8/0	21/0	40/0	55/3	58/13	72/57	17/0	31/0	46/9	57/22	59/47	25/4	46/27	44/25	57/44
Ausgelaugter Tschernosem Smolnitza	75/2	59/1	66/0	71/0	68/7	81/20	82/50	62/0	52/0	73/10	77/20	72/43	70/5	60/9	66/20	77/34
Wiesen Solontschak-Solonetz	20/10	3/0	2/0	13/0	45/4	62/21	96/89	4/0	25/0	63/20	73/43	95/89	5/0	19/3	39/22	61/48

zentration 0,1%. Bei dem zimtfarbigen Waldboden wurden z.B. unter dem Einfluss von 0,1% „Verdickung AN“ 62% Krümel > 1 mm bzw. 21% bei der Konzentration 0,05% gebildet. Die Konzentration 0,1% übt eine deutliche positive Wirkung bei der Bildung von Krümel > 1 mm auch bei dem Tschernosem-Smolnitza aus. Bei den Versuchen mit zerriebenen Böden (Tabelle 1) konnte festgestellt werden, dass „Soiluck“ besser zur Bildung von Krümel > 1 mm als „Verdickung AN“ and „Solakrol“ beiträgt (die Konzentration 0,05% entspricht, der Wirkung nach, der Konzentration 0,1% der beiden anderen Polymere). Dieser Vorteil von „Soiluck“ kam jedoch bei den Versuchen mit natürlichen Proben nicht zum Vorschein.

Tabelle 2

Gehalt an wasserfesten Krümel bei Behandlung von Böden mit Polymeren bei natürlicher Strukturzusammensetzung

Zähler > 0,25 mm grosse Krümel; Nenner > 1 mm grosse Krümel

Bodentyp	Nicht behandelter Boden	Polymere bzw. Konzentration in %										
		Verdickung AN				Solakrol				Soiluck		
		0,02	0,05	0,1	0,5	0,02	0,05	0,1	0,5	0,02	0,05	0,1
Ausgelaugter zimtfarbiger Waldboden	18/5	69/7	77/21	91/62	98/71	62/5	60/4	88/49	96/76	58/8	84/50	91/69
Grauer Waldboden	22/2	71/8	79/22	85/44	95/64	79/18	79/16	87/46	90/62	74/23	85/48	89/65
Ausgelaugter Tschernosem-Smolnitza	75/2	93/3	93/45	89/44	94/75	86/2	85/3	85/20	95/69	85/5	87/25	94/42
Wiesen Solontschak-Solonetz	19/10	41/15	67/42	81/62	87/79	neopr/6	64/41	83/64	92/85	31/16	47/35	70/65

Durch die Behandlung mit 0,1% „Verdickung AN“ konnte bei allen Böden eine mehrfache Erhöhung der Wasserdurchlässigkeit und eine bedeutende Abnahme der Härte beim Abschneiden erzielt werden.

Bei der Lösung der Frage nach der optimalen Konzentration sind selbstverständlich nicht nur die Ergebnisse der Laboratoriumsversuche, sondern auch die Art und Weise in welcher die Pflanzen reagieren, zu berücksichtigen. Die Ergebnisse der Gefässversuche zeigen, dass unter dem Einfluss der Behandlung von ausgelaugtem und podsoliertem zimtfarbigen Waldboden mit „Verdickung AN“ das Wurzelsystem sowohl bei Tabakstecklingen als auch bei Paprika stark zugenommen hat (Tabelle 3 und 4.) Durch Versuche mit steigenden „Verdickung AN“-Konzentrationen konnte eine gute Korrelation zwischen der allmählichen Strukturverbesserung und der Zunahme der Wurzelmenge mit der Steigerung der Polymerkonzentration festgestellt werden. Die diesbezüglichen Daten weisen darauf hin, dass die Pflanzen auf die Verbesserung der physikalischen Bodenverhältnisse sehr

Tabelle 3

Gefässversuchsergebnisse bei Behandlung des podsolierten zimtfarbigen Waldbodens mit „Verdickung AN" zur Produktion von Tabakstecklingen, 1962

Versuchsreihen	Gesamtzahl der Pflanzen		Gewicht von 100 Pflanzen in lufttrockenem Zustand g		% der Wurzeltrockensubstanz
	Aufgelaufen	Zum Verpflanzen geeignet	Stengel u. Wurzeln	Wurzeln	
Nicht behandelter Boden	210	104	7,9	0,2	4,6
Bodenoberflächenschicht (1 kg) mit 0,1% „Verdickung AN" behandelt	265	103	8,4	0,4	8,6
Gesamtbodenmenge (7 kg) mit 0,1% „Verdickung AN" behandelt	318	141	8,5	0,6	9,2

gut reagieren. Eine deutlich positive Wirkung auf den Ertrag konnte jedoch nur bei der empfindlichen Paprikasorte „Siwrija 600" erzielt werden. Es ist dabei festzustellen, dass der Wasserverbrauch je Trockensubstanzeinheit bei dem behandelten Boden geringer war (302 g Wasser je 1 g Pflanzenmasse bzw. 449 g Wasser je 1 g Pflanzenmasse bei dem nichtbehandelten Boden). Das Fehlen einer deutlichen Ertragssteigerung im Gefässversuch bei der Hybridensorte „D 103 × Siwrija 600" ist unseres Erachtens auf die stärkere Lebenskraft der Hybridensorten zurückzuführen, welche die Bodennährstoffe intensiver und vollständiger ausnutzen. Dieses Vermögen der Hybridensorte wird durch die absoluten Ertragswerte bestätigt, welche bedeutend höher als bei der Sorte „Siwrija 600" sind.

Durch die Untersuchungen an der Wirkungsdauer der Polymere konnte festgestellt werden (Tabelle 4), dass nach zwei Jahren Paprikaanbau die Unterschiede im Strukturzustand immer noch nennenswert zugunsten des behandelten Bodens sind. Im Zusammenhang damit war auch das Volumengewicht des Bodens bei den behandelten Varianten bedeutend niedriger (1, 13) als dasjenige der nichtbehandelten (1, 28).

Infolge des grösseren Bodenvolumens, über welches die Pflanzen verfügen, wird im Felde der Vorteil der Pflanzen mit mächtigerem Wurzelsystem den Ertrag stärker beeinflussen.

Zusammenfassend kann festgestellt werden, dass die Anwendung der Polymere vor allen Dingen bei dem grauen, zimtfarbigen und dem Solontschak-Solonetzboden von Bedeutung sein kann. Bei diesen Böden sind auch Konzentrationen die niedriger als 0,1% sind, beachtenswert, da sie eine bedeutende Verbesserung ihres Strukturzustandes bedingen. In Bulgarien steht eine bedeutende Zunahme der Bewässerungsflächen auf der Tagesordnung, weshalb die Frage nach der Verbesserung der Bodenstruktur eine grosse Aktualität erlangen wird.

Tabelle 4

Gefässversuchsergebnisse bei Behandlung des ausgelaugten zimtfarbigen Waldbodens mit „Verdickung AN"

Versuchsreihen	Schotenertrag g	Schotenertrag relative Werte	lufttrockene Wurzeln g	lufttrockene Wurzeln relative Werte	Krümel > 1 mm nach Beendigung der Pflanzenvegetation %
Paprikasorte „Sivrija 600", 1962					
NPK	334	100	7,6	100	15
NPK + 0,1% „Verdickung AN"	435	130	15,7	207	34
Nachwirkung der Behandlung des Bodens im Jahre 1963					
NPK	440	100	5,7	100	18
NPK + 0,1% „Verdickung AN"	469	106	8,4	147	35
Versuch mit steigenden „Verdickung AN"-Dosen Paprikasorte „D103 × Sivrija", 1963					
NPK	479	100	6,7	100	5
NPK + 0,1% „Verdickung AN"	496	104	8,2	128	11
NPK + 0,02% „Verdickung AN"	490	102	9,2	137	17
NPK + 0,05% „Verdickung AN"	503	105	10,6	159	27
NPK+ 0,1% „Verdickung AN"	488	102	10,6	159	34
NPK + 0,1% „Verdickung AN" nur die 3 cm Bodenschicht behandelt.	491	103	7,2	108	
NPK + 0,1% „Verdickung AN" nur die 6 cm Bodenschicht behandelt.	499	104	9,6	143	

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ZUSAMMENFASSUNG

Es wurde die Wirkung der Polymere: „Verdickung AN", „Solakrol" und „Soiluck" zur Verbesserung der Struktur und einiger physikalischer Eigenschaften von grauen Waldböden, ausgelaugten zimtfarbenen Waldböden, Solontschak-Solonetzböden und ausgelaugten Tschernosem-Smolnitzaböden untersucht.

Festgestellt wurde, dass die wasserstabilen Aggregate, welche sich unter dem Einfluss der schwächeren Konzentrationen gebildet haben, vorwiegend zu der kleinkörnigen Fraktion 1—0.25 mm zählen. Zur Bildung von wasserbeständigen Aggregaten Grösse > 1 mm zeigt „Soiluck" guten Einfluss bei Konz. von 0,02—0,05%, während „Verdickung AN" und „Solakrol" diese Wirkung bei 0,05—0,1% zeigen.

Durch Gefässversuche wurde eine gute Korrelation zwischen der allmählichen Strukturverbesserung und der Zunahme der Wurzelmenge mit der Steigerung der Polymerkonzentration festgestellt.

SUMMARY

The influence of the polymers „Verdickung AN", „Solakrol" and „Soiluck" on the improvement of the structure and of some physical properties of grey forest soils, leached cinnamon coloured forest soils, solonchak-solonetz and leached chernozem-Smolnitza soils was investigated.

It was established that the water stable aggregates, formed under the influence of a lower concentration, are considered to belong especially to the microgranular fraction 1—0,25 mm. „Soiluck" proved to have a good influence on the formation of > 1 mm water stable aggregates in concentrations of 0.02—0.05%, whereas for „ Verdickung AN" and „Solakrol" a similar influence was exerted in concentrations of 0.05—0.1%.

By pot experiments a good correlation between the gradual structure improvement and increase in the amount of roots with the increasing polymer concentrations was established.

RÉSUMÉ

On a étudié l'influence des polymères „Verdickung AN", „Solakrol" et „Soiluck" en vue de l'amélioration de la structure et de quelques propriétés physiques des sols gris de forêt, sol de forêt „canelle" lévigé, solontchak-solonetz et chernozem-smolnitza.

Les agrégats stables à l'eau, formés sous l'influence d'une concentration plus faible, se sont avérés comme appartenant surtout à la fraction microgranulaire de 1—0,25 mm „Soiluck"

prouve qu'il a une influence favorable sur la formation des agrégats > 1 mm stables à l'action de l'eau dans les concentrations de 0,02 à 0,05% et „Verdickung AN" et „Solakrol" exercent une influence similaire dans les concentrations de 0,05 à 0,1%.

Par des expériences en vases on a établi une corrélation favorable entre l'amélioration graduelle de la structure et l'augmentation du système radiculaire toutes les deux dues aux concentrations croissantes du polymère.

DISKUSSION

L. DE LEENHEER (Belgien). Haben Sie durch Feldversuche festgestellt, dass die Ertragserhöhung eine *ökonomisch-vertretbare Anwendung* der Polymere möglich macht?

W. GALEWA. Wir haben noch keine Feldversuche durchgeführt, welche uns die Möglichkeit geben, den ökonomischen Effekt der Polymere festzustellen. In der Landwirtschaft Bulgariens sind aber Intensivkulturen (Gemüse und technische Kulturen) sehr stark vertreten, und ich bin der Meinung, dass die Polymere eine gewisse Rolle unter Bewässerungsverhältnissen als Krustenbekämpfungsmittel spielen können.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 28

DIE WIRKUNG DER PRÄPARATE „CH 5" UND „CM 1" AUF ETLICHE EIGENSCHAFTEN KÜNSTLICHER BODENAGGREGATE

J. CSAPÓ-MIKLÓSI, R. DOBAI, J. KAIN [1]

Das Problem der Strukturstabilisatoren gewinnt sowohl bei uns, wie auch im Ausland von Tag zu Tag an Bedeutung.

Über diese Frage hat Tiurin bereits im Jahre 1954 geschrieben: „...wird sich eine vom wirtschaftlichen Standpunkt rentable Modalität zur künstlichen Bildung der Struktur finden lassen, so ergeben sich in unserer Agrotechnik grosse Änderungen, deren Folgen man vielleicht mit jenen Umwälzungen wird vergleichen können, die sich seinerzeit in Westeuropa durch die allgemeine Anwendung der mineralischen Düngemittel abspielten, und vermittels derer der durchschnittliche Ernteertrag der Gramineen, welcher bis dahin an Hand der Kleekultur 15 dz/ha erreicht hatte, auf 25—30 dz anstieg, d.h. sich verdoppelte " (Tiurin, 1954).

Nachdem die Idee der Bildung künstlicher Bodenaggregate im Jahre 1932 in der Sowjetunion, durch Joffe und Talmud (Werschinin, 1958) aufgeworfen worden war, gelangte in der Landwirtschaft erstmalig in den Vereinigten Staaten ein Präparat unter dem Namen „Krilium" oder CRD-189, zur Anwendung. Dies war ein in Wasser löslicher Polyelektrolyt von hohem Molekulargewicht. Ihm gesellte sich das CRD-189 hinzu. Über die stabilisierende Wirkung dieser Präparate wurde nach mehrjährigen Forschungen, im Jahre 1951 Mitteilung gemacht (Nehéz, 1955; Krámer, 1955). Seither hat sich die Zahl der Stabilisatoren in den Vereinigten Staaten vervielfältigt. So sind aufgekommen: HPAN (ein hydrolisiertes Derivat des Polyakrylnitrils), VAMA (Polymer der Vinylazetatmaleinsäure), CMC (Karboilmethylzelluloseverbindungen), IMBA (ein Polymer von Isobuthylen und Maleinsäure). Nachdem man verschiedene Erzeugnisse erprobt hatte, hat man sich in der UdSSR während den letzten Jahren etlichen Plasten wie Polyakrylonitril, hydrolisiertes Polyakrylonitril, Polyakrylamid, dem Kopolimer von Metakrylsäure mit Metakrylamid, dem K-4, K-6, K_1-6, K_2-6, K_3-6 usw. zugewandt (Gussak, 1961; Achmedow et al., 1962). Es sei bemerkt, dass das Präparat K-4, und K-6 sich als ein den anderen überlegener Stabilisator erwiesen hat (Aripow, 1963). In der Ungarischen Volksrepublik wurde 1955 ein Derivat vom Typ des HPAN unter dem Namen „Solakrol"

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herausgebracht, das eine 20%ige wässerige Lösung von Na-Polyakrylat ist (Krámer, 1955). In der DDR gelangt ebenfalls eine Reihe von Kunstharzen zur Anwendung, wie z.B.: das monomere Ca-Akrylat, das hydrolysierte Polyakrylnitril, (VEB Chemische Werke Schkopau), Karbamid- und Formaldehydharze (VEB Leunawerk), Vestopal H — ein Polyesterharz (Chemische Werke Hüls A.G.), Epilox EGR-19 — ein Epoxydharz (VEB Leunawerk), Pelasal 59, 136 G (Kunstharze auf Polyvinylazetatbasis — VEB-Kittwerk Pirna). Von all diesen Präparaten haben sich das monomere Ca-Akrylat und die Karbamid- und Formaldehydkunstharze als am geeignetsten erwiesen (Fiedler und Czerney, 1963). Die Forschungen auf diesem Gebiet haben in fast allen Ländern eine grosse Verbreitung gefunden, so dass die Zahl der Strukturstabilisatoren von Tag zu Tag wächst.

In Rumänien wurden die ersten Studien in dieser Richtung von Lungu mit CRD-186 — ein Erzeugnis der V.St.A. — (Lungu, 1958) und von Csapó mit „Solakrol" — in der Ungarischen V R hergestellt — (Csapó, 1959) vorgenommen. Gleichzeitig erschien auch die erste Arbeit über die Wirkung der inländischen Polyelektrolyte BP-1 und BP-2 (Popa und Bratu, 1960). Dann folgten weitere Arbeiten über die Wirkung des Äthylesters der Polyakrylsäure (Csapó et al., 1961) der Polyakrylsäure (Csapó et al., 1963) und des Kopolymers „CH 5" (Csapó, Dobai und Kain, 1963).

In der Zwischenzeit wurden die Untersuchungen über die stabilisierende Wirkung des Kopolymers CH 5 vertieft und die Resultate mit jenen eines neuen Präparates, CM 1, verglichen. Beide Substanzen sind synthetische Erzeugnisse des Instituts „Chimigaz" aus Mediasch.

Vorliegende Arbeit bringt nun die mit diesen beiden Erzeugnissen erzielten Ergebnisse. Beide sind wertvolle Stabilisatoren.

MATERIAL UND METHODE

Unsere Untersuchungen wurden unter Laborbedingungen vorgenommen. Ihren Gegenstand bildeten: die Horizonte A_1 und A_2 eines Pseudogley-Lessivé (Böden Nr. 3 und 4); der Horizont A einer Parabraunerde (Boden Nr. 15); die Horizonte A' und A''g eines ausgelaugten, in seiner Textur degradierten Tschernosems (Böden Nr. 11 und 12); der Horizont A eines hellbraunen Abhangbodens (Boden Nr. 9); der Horizont A eines Wiesenbodens (Boden Nr. 7) und der Horizont (A) eines sandig-lehmigen, schwach humosen Alluvialbodens (Boden Nr. 19). Etliche kennzeichnende analytische Daten dieser — nicht bebauten — Böden sind in Tabelle 1 wiedergegeben.

Bestimmt wurde die Wasserbeständigkeit der wertvollsten Aggregate, also jener von 3—1 mm Ø (Krámer, 1952; Terts, 1954). Als wasserfest wurden die Aggregate betrachtet, die nach nassem Sieben auf dem Sieb von 1 mm Maschenweite zurückblieben. Hierbei wurden sowohl die natürlichen wie auch die künstlichen, durch trockenes Sieben gewonnenen Aggregate erprobt. Im Falle der künstlichen Aggregate gelangte gestossener und durch

Tabelle 1

Charakterisierung der untersuchten Böden

Nr. des Bodens	Bodentyp	Horizont	Tiefe in cm	hy	pH H_2O	T—S	S	T	V %
						Milliäquivalente pro 100 g Boden			
3	Pseudogley-Lessivé	A_1	0—7	2,72	5,54	6,98	11,79	18,77	62,81
4		A_2	10—30	2,21	4,94	10,21	4,22	14,43	29,24
15	Parabraunerde	A	0—20	2,68	5,57	8,06	12,68	20,74	61,14
11	Ausgelaugter Tchernosem	A'	0—15	4,06	5,88	7,75	27,55	35,30	78,05
12		A''	30—50	4,35	6,10	5,25	30,42	35,67	85,28
9	Hellbrauner Abhangboden	A	0—15	3,60	7,40	—	—	—	—
7	Wiesenboden	A	0—18	5,13	7,55	—	—	—	—
19	Sandig-lehmiger, schwach humoser Alluvialboden	A (A)	0—20	1,46	7,62	—	—	—	—

das 1 mm Sieb durchgesiebter Boden zur Anwendung, der mit Wasser und den stabilisierenden Substanzen behandelt wurde. Diese wurden in wässeriger Lösung von 1,5—2% beigemischt. Dann wurde die zur Erreichung der unteren Plastizitätsgrenze notwendige Wassermenge zugesetzt.

Die Wasserbeständigkeit wurde mit dem Kazo-schen Apparat (Kazo, 1958) in vierfacher Wiederholung, nach vorangegangener rascher Anfeuchtung von 30′ und anschliessenden 30 Dekantierungen binnen 15′, bestimmt.

Die Druckfestigkeit der natürlichen und künstlichen Aggregate von 2,5—3 mm Ø wurde mit dem von Pop gebauten Apparat gemessen. Mit jeder Bodenprobe wurden 50—100 Bestimmungen vorgenommen.

ERGEBNISSE UND BESPRECHUNG

Die Ergebnisse der Untersuchungen sind in Abbildung 1 wiedergegeben. Für jeden Horizont wurden graphisch dargestellt: die Wasserbeständigkeit in % für die natürlichen Aggregate, für die mit „Solakrol" 0,1% erzielten künstlichen Aggregate, für die Aggregate mit Wasser und für die Aggregate mit CH 5 und CM 1. Letztere beide Präparate gelangten dabei in Konzentrationen von 0,02, 0,04, 0,08, 0,12, 0,16, 0,20 und 0,24%, gemessen am Gewicht des lufttrockenen Bodens, zur Anwendung. Weiterhin sind dargestellt die Druckfestigkeit der natürlichen Aggregate, der mit Wasser zubereiteten Aggregate, sowie der mit denselben Konzentrationen von Stabilisatoren zubereiteten künstlichen Aggregate.

Um die mit der angewandten Methode erzielten Resultate über die Wasserbeständigkeit deuten zu können, haben wir folgende Skala eingeführt: sehr gute Wasserbeständigkeit (90—100%), gute Beständigkeit (25—90%), hinreichende Beständigkeit (50—75%), schwache Beständigkeit (25—50% sehr schwache Beständigkeit (< 25%).

Im Falle der *natürlichen Aggregate* wurde eine sehr gute Wasserbeständigkeit bei den Böden Nr. 15 und 11 festgestellt. Gute Wasserbeständigkeit zeigten alle übrigen Horizonte, mit Ausnahme der Böden Nr. 4 (hin-

reichend) und Nr. 19 — letzterer praktisch ohne hydrische Stabilität. Dabei fand die Feststellung, dass die Aggregate der oberen, humushaltigen Horizonte, die sich unter der natürlichen Vegetation bilden, eine gute Wasserbeständigkeit haben, ihre Bestätigung (Lungu, 1950—1951; Dvoracsek et al., 1952).

Eine Wasserbeständigkeit der *mit Wasser* dargestellten *künstlichen Aggregate* gab es praktisch nicht.

„Solakrol" wurde im Verhältnis von 0,1‰ des Bodengewichtes zugesetzt. Mit Ausnahme der Böden Nr. 3, 4 und 15 — wo die Ergebnisse weit unter den Wasserbeständigkeitswerten der natürlichen Aggregate lagen — bewegten sich die gemessenen Indexe im allgemeinen auf dem natürlichen Niveau. Allein im Falle des sandigen Bodens (Nr. 19) war die Wasserbeständigkeit eine bedeutend höhere.

Die mit den verschiedenen Konzentrationen von CH 5 erzielten Kurven sind zweierlei Art: die eine Art zeigt ein Maximum bei der Konzentration von 0,20‰ (Böden Nr. 4, 15 und 7); die andere Art hat ein Maximum bei der Konzentration von 0,12‰ (Boden Nr. 11) oder 0,16‰, worauf dann bei der Konzentration von 0,20‰ ein mehr oder weniger betonter Abfall eintritt, um endlich im weiteren Verlauf wieder ein Ansteigen der Wasserbeständigkeit aufzuweisen (Böden Nr. 3, 12, 9 und 19). Im Falle des Bodens Nr. 11 liegen die beiden Maxima bei 0,08 und 0,12‰[1]. Die Maxima beider Kurventypen entsprechen praktisch der natürlichen Wasserbeständigkeit, wovon nur der Boden Nr. 19 (lehmiger Sand) eine Ausnahme bildet, indem das künstliche Aggregat bedeutend stabiler ist.

Die mit CM 1 erzielten Kurven sind ebenfalls von zweifachem Typ: der eine Typ hat nur ein Maximum bei den Konzentrationen von 0,12—0,16‰ (Böden Nr. 19 und 9), der andere hat zwei Gipfelpunkte. Das erste Maximum liegt zwischen den Konzentrationen von 0,08—0,16‰; darauf folgt ein mehr oder weniger starker Abfall (Böden Nr. 3, 4, 12, und 7, bzw. 15 und 11[2]; das zweite Maximum entspricht der Konzentration von 0,20 oder 0,24 ‰. Die Kurven von CM 1 zeigen im allgemeinen (mit Ausnahme des Bodens Nr. 11) höhere Wasserbeständigkeiten, als jene, die mit CH 5 erzielt wurden. Die Werte bleiben in der Nähe der Wasserbeständigkeit der natürlichen Aggregate, bei den Böden Nr. 4 und 19 liegen sie aber viel höher.

Die Ergebnisse mit CH 5 und CM 1 zeigen, dass das Präparat CM 1 eine betontere stabilisierende Wirkung hat; in 5 Fällen (Böden Nr. 3, 15, 12, 9 und 7) wurde schon bei einer Konzentration von 0,04‰ eine gute Wasserbeständigkeit — um 80‰ — erreicht, in 2 Fällen (Böden Nr. 15 und 19) war die Wasserbeständigkeit ebenfalls höher, als bei Anwendung von CH 5 und nur in einem Fall (Boden Nr. 11) sind sich die Wirkungen beider Präparate praktisch gleich. Im Vergleich zu „Solakrol" hat CH 5 in 3 Fällen (Böden Nr. 3, 4 und 15) eine höhere, in 2 Fällen (Böden Nr. 11 und 12) eine etwa gleichwertige, und in 3 Fällen (Böden Nr. 9, 7 und 19) eine geringere Wirkung gezeigt. Das Präparat CM 1 hat sich in 3 Fällen

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[1] Bei den Böden 12, 9, 11 ist die Existenz der zwei Gipfelpunkte nicht gesichert.
[2] Bei den Böden 15, 11 ist die Existenz der zwei Gipfelpunkte nicht gesichert.

(Böden Nr. 3, 4 und 15) als überlegen, und bei allen anderen Böden als dem „Solakrol" etwa gleichwertig erwiesen.

Beide Präparate, das CH 5 wie das CM 1 hatten selbst in den minimalen Konzentrationen von 0,02, bzw. 0,04% eine sichere, stabilisierende Wirkung, indem alle ihre Werte höher lagen als bei den nur mit Wasser zubereiteten Aggregaten.

Im Laufe der Untersuchungen konnte keine betonte Auswirkung des pH- und des V-Wertes auf die Wasserbeständigkeit der künstlichen Aggregate aus den Oberflächenhorizonten festgestellt werden.

Der Charakter der Kurven entspricht im allgemeinen der Auffassung, die sich über das Vorhandensein einer Wasserstoffbindung zwischen den OH-Gruppen der Tonmineralien und den aktiven funktionellen Gruppen der Stabilisatoren herausgebildet hat (Kazó, 1958; Emerson, 1959; Gussak, 1961; Maslenkowa, 1961; Aripow et al., 1963; Davidescu, 1963; Fiedler und Czerney, 1963).

So sollen sich stabile Netze bilden, die die Elementarteilchen des Bodens in wasserbeständige Aggregate zusammenfassen.

Aripow und Mitarb. (1963) haben während ihren Versuchen mit dem Präparat K-4 ein Höchstmass an stabilisierender Wirkung bei der Konzentration von 0,15% erreicht, was sehr nahe an unseren Konzentrationen mit maximalem Effekt liegt (vgl. auch Achmedow, et al., 1962). Der Umstand, dass in etlichen Fällen die Kennlinie 2 Maxima aufweist, liesse sich vielleicht folgenderweise erklären: in der Ton-Fraktion der untersuchten Böden herrschen Beidellit (50—65%) und Illit (35—50%) (Treiber und Bálint, 1963) vor, und eine jede dieser Komponenten verhält sich den Strukturstabilisatoren gegenüber anders.

Die Daten über die Druckfestigkeit der natürlichen Aggregate zeigen, dass die oberen Horizonte der Böden, die sich unmittelbar unter der natürlichen Vegetation befinden, von diesem Standpunkte aus voneinander stärker abweichen als in bezug auf die Wasserbeständigkeit (Csapó und Bálint, 1958). So weisen die Böden Nr. 11, 12 und 7 (ausgelaugter Tschernosem und Wiesenboden) eine hohe, der Boden Nr. 19 (lehmiger Sand) eine ganz geringe Druckfestigkeit auf.

Die Widerstandsfähigkeit gegenüber Druck der mit CH 5 dargestellten künstlichen Aggregate ist — mit Ausnahme des Bodens Nr. 19 —bei der Konzentration von 0,04% höher als bei der nächstfolgenden, ein Phänomen, das bei den Aggregaten mit CM 1 nicht beobachtet werden kann.

Bei den mit einem der beiden Präparate, bzw. mit Wasser dargestellten künstlichen Aggregate geht der Zusammenhang zwischen Textur (hy), Bodentyp und Druckfestigkeit aus folgendem hervor: a) Beiden Böden mit hy[1] $< 2{,}75$ beträgt die Druckfestigkeit der Aggregate weniger als 250 g /Aggregat (Böden Nr. 3, 4 und 19); b) Von den Böden mit hy $> 3{,}60$, liegt im Horizont *A'* des ausgelaugten Tschernosems (Boden Nr. 11) die Druckfestigkeit der künstlichen Aggregate unterhalb des Grenzwertes von 700 g Aggregat; die podsolierte Braunerde gehört, vom Standpunkte der Druckfestigkeit, ebenfalls zu dieser Kategorie; c) von den Böden mit hy $> 3{,}60$,

[1] hy — Hygroskopizitätswert nach Kuron.

haben der Wiesenboden und der hellbraune Abhangboden (Böden Nr. 7 und 9) bedeutend höhere Druckfestigkeiten, indem die untere Schwelle bei ca. 300 g und die obere zwischen 1 200 und 1 900 g/Aggregat liegt. Der Horizont A''g des texturell degradierten, ausgelaugten Tschernosems — der sich dem Wiesenboden nähert — liegt zwischen den letzten beiden Gruppen, vor allem in bezug auf die Druckfestigkeit der mit Wasser hergestellten Aggregate.

Die Resultate bei den mit Wasser erzielten künstlichen Aggregaten lagen in der Mehrzahl der Fälle höher als bei den mit Stabilisatoren zubereiteten Aggregaten. Somit haben also die Strukturstabilisatoren bezüglich der Druckfestigkeit der Aggregate keine postive Wirkung gezeitigt.

Wie auch im Falle der natürlichen Aggregate, so hat es sich auch bei den künstlichen Aggregaten gezeigt, dass ihre Druckfestigkeit für die Bodenart kennzeichnender ist als ihre Wasserbeständigkeit.

Die Druckfestigkeit der künstlichen Aggregate ist im allgemeinen bedeutend geringer, als jene der natürlichen Aggregate. Ausnahme bilden die mit Wasser entstehenden Aggregate, die ähnliche Werte wie die natürlichen Aggregate ergaben und der mit CM 1 0,20$^0/_0$ behandelte Boden Nr. 7 (Wiesenboden), wo die Werte höher lagen. Im Falle des Bodens Nr. 19 (lehmiger Sand) ist die Resistenz der natürlichen Aggregate gegenüber Druck sehr gering, so dass die Festigkeit der künstlichen Aggregate mit CH 5 und CM 1 höher liegt.

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ZUSAMMENFASSUNG

Die natürlichen und künstlichen Aggregate aus den oberen, humushaltigen Horizonten der unmittelbar unterhalb der natürlichen Vegetation liegenden Böden unterscheiden sich voneinander nicht so sehr vom Standpunkte der Wasserbeständigkeit, als viel eher von jenem der Druckfestigkeit.

Die Wasserbeständigkeit der mit „Solakrol" hergestellten künstlichen Aggregate liegt auf dem Niveau der natürlichen Aggregate, mit Ausnahme des Pseudogley-Lessivé und der Parabraunerde, wo die Werte geringer sind, und des lehmigen Sandes, wo sie bedeutend höher liegen.

Mit den Präparaten CH 5 und CM 1 waren bei allen Böden die Aggregate etwa in demselben Masse wasserbeständig, wie die natürlichen Aggregate, nur der lehmige Sandboden ergab bedeutend höhere Werte.

Das Präparat CM 1 trat dadurch hervor, dass es in den meisten Fällen schon in der Konzentration von 0,04% des Bodengewichtes erhöhte Werte der Wasserbeständigkeit ergab.

Im allgemeinen ertragen die künstlichen Aggregate nur bedeutend geringere Druckbelastungen als die natürlichen.

Somit leisten die erwähnten Stabilisatoren einen positiven Beitrag zur Bildung wasserbeständiger Aggregate, sind aber bezüglich der Steigerung der Druckfestigkeit der Aggregate wirkungslos.

SUMMARY

The natural and artificial soil aggregates of the humus surface horizons, do not differ so much by their water stability, as rather more by their pressure resistance.

The water stability of the artificial aggregates prepared with „Solakrol" was at the level of the natural aggregates, except the loamy illuvial podzolic soils and in the podzolised brown soils, where the values were lower, and in the loamy sand soils, where they were significantly higher.

The aggregates of all soils, obtained with the preparations CH 5 and CM 1 were equally water-stable like the natural ones, except the loamy sand soils where they showed significant higher values.

The CM 1 product is standing out by the fact that, in most cases, it presented increased values of water stability already at the concentration of 0.04%, as related to soil weight.

Generally, the pressure resistance of artificial aggregates is much lower than that of natural ones.

Consequently, the above mentioned soil-aggregate stabilizers contribute positively to the formation of water stable aggregates, but are not efficient concerning the pressure resistance of aggregates.

RÉSUMÉ

Les agrégats naturels et artificiels des horizons supérieurs, humifères, diffèrent entre eux moins du point de vue de la stabilité à l'eau, que du point de vue de leur résistance à la pression.

La stabilité à l'eau des agrégats artificiels préparés au „Solakrol" est au niveau des agrégats naturels, à l'exception des sols podzoliques argilo-illuviaux et des sols bruns podzolisés dont les valeurs sont plus petites et des sables limoneux elles sont sensiblement plus grandes.

Traités avec les produits CH 5 et CM 1 les agrégats de tous les sols présentent la même stabilité à l'eau que les agrégats naturels, seul le sol limo-sablonneux a donné des valeurs sensiblement plus grandes.

Le produit CM 1 s'est affirmé par le fait, que, dans la plupart des cas on est parvenu à obtenir des valeurs augmentées de la stabilité à l'eau, même pour des concentrations de 0,04% par rapport au poids du sol.

En général, les agrégats artificiels présentent des résistances à la pression sensiblement plus réduites que ceux naturels.

Ainsi, les stabilisateurs cités contribuent, d'une manière positive, à la formation d'agrégats stables à l'eau, mais ils manquent de toute efficence quant à l'augmentation de la résistance à la pression des agrégats.

DISKUSSION

D. ELBERT: (Deutsche Demokratische Republik). Wir suchen nach Polymerisaten mit nur kurzer Wirksamkeit, um damit die Böden der Zuckerrübenfelder besprühen zu können. Die Aussaat der Rüben erfolgt mit Einzelkonsummaschinen und mit einzelfrüchtigem Saatgut. Es kommt darauf an, dass jedes Korn aufläuft, und sich nicht durch eine regenbedingte Bodenverkrustung eine Neusaat notwendig macht.

Ist Ihre Substanz ein Abfallprodukt, das sich für diesen Zweck eignen würde?

I. CSAPÓ. Weder CH 5 noch CM 1 sind Abfallprodukte. Sie wurden speziell zu diesem Zweck hergestellt.

M. H. B. HAYES (U. K.). Can you please outline the chemical nature of CH 5, CM 1 and „Solakrol" and what are your opinions on the mechanism of aggregation of these compounds

I. CSAPÓ. CH 5 ist ein Kopolymer aus Methyl-Metakrylat und Metakrylsäure. CM 1. ist ein teilweise hydrolyisiertes Polyakrylamid.

Ihre Wechselwirkung mit dem Boden insbesondere des Polyakrylamids ist aus der Literatur bekannt.

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BODENSTRUKTUR UND LEBENSBEDINGUNGEN DER PFLANZEN

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Seit mehreren Jahrzehnten bildet das Problem der Bodenstruktur den Gegenstand einer scharfen Diskussion in der Weltliteratur für Bodenkunde und Agronomie. Im Laufe dieser Diskussion werden extremste Ansichten über die Rolle der Struktur für die Bodenverhältnisse des Pflanzenlebens, über deren Rolle für die Fruchtbarkeit des Bodens dargelegt und verteidigt.

Ein unermessliches Tatsachenmaterial sowie zahlreiche theoretische Überlegungen geben einen festen Anhalt dazu, die Identität der Begriffe Bodenstruktur und Fruchtbarkeit des Bodens zu verneinen.

Neue Erkenntnisse ermöglichen es anzunehmen, dass die Bodenstruktur einen wesentlichen Einfluss auf das Wachstum der Pflanzen ausüben kann, nur indem sie den Komplex der im Boden herrschenden physikalischen Verhältnisse verändert: die Dichte des Bodens, die Wasser- und Wärmeregime desselben und die damit in Verbindung stehende mikrobiologische Tätigkeit, sowie die Erzeugung von für die Pflanzen zugänglichen Nährsubstanzen im Boden. Aus dieser Behauptung folgt unmittelbar, dass die Bodenstruktur wenig Bedeutung hat, wenn die Regelungstätigkeit der Bodenverhältnisse durch Klima- bezw. Witterungsbedingungen getragen werden oder der günstige Einfluss der Bodenstruktur durch sinnvolle Tätigkeit des Menschen ersetzt wird. Im letzteren Falle wird allerdings die Agrikultur bei weitem kraftraubender und mit grösserem Aufwand an Energie verbunden und die erhaltenen Erzeugnisse werden kostspieliger.

VERSCHIEDENE BODENSTRUKTUREN

Für die feste Phase des Bodens sind drei Zustände denkbar: 1) der primären (elementaren) mechanischen Teilchen; 2) der Mikroaggregate; 3) der Makroaggregate.

Die allgemeinen thermodynamischen Überlegungen sprechen dafür, dass für schwere Bodenarten die aus primären Teilchen gebildeten Systeme

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unbeständig sind. Das vorhandene umfangreiche Tatsachenmaterial zeugt davon, dass nahezu 100% der Ackerböden des Landes zu 80 und mehr Prozent aus Mikroaggregaten bestehen.

Die Mikroaggregate werden von uns als Gebilde sekundärer Art angesehen, die aus primären mineralischen bezw. organomineralischen Teilchen bestehen und deren Entstehung auf Koagulation- bezw. Agglomerationsprozesse an den primären Teilchen zurückzuführen ist.

Man darf gegenwärtig die Theorie als durchaus begründet ansehen, die die grössten Abmessungen der primären Teilchen, welche bei Koagulation zusammenzukleben vermögen, sowie die grössten Abmessungen der dabei entstehenden Aggregate, festlegt. Für sphärische Teilchen von gleicher Grösse gibt B.W. Derjagin eine Gleichung an, in der der Zusammenhang zwischen der Haftkraft *(Fh)* und dem Teilchenhalbmesser *(r)* dargestellt ist: $Fh = 2\pi r\sigma$. Dieses bedeutet, dass die Haftkräfte der Dispersität der Teilchen proportional sind. Aus dieser Gleichung ist leicht zu ersehen, dass bei Teilchengrössen von $5 \cdot 10^{-2}$ mm die Haftkräfte das Eigengewicht der Teilchen übersteigen. Demzufolge verursacht die Koagulation die Bildung nur von solchen Mikroaggregaten, deren Grösse einige Hundertstel bezw. einige Zehntel Millimeter beträgt.

In der allerletzten Zeit hat Masslönkowa bei der Untersuchung der Wechselwirkung eines Polymers (Polyacrylamid) mit einem Bodenmineral (Kaolinit) gezeigt, dass die Koagulationsprozesse mit den Entstehungsprozessen von Makroaggregaten nicht übereinstimmen. Masslönkowa hat festgestellt, dass die Entstehung von Mikroaggregaten sich in einer direkten Abhängigkeit von der Koagulationsfähigkeit des Polymeres und dessen Adsorptionswert befindet. Wasserbeständige Makroaggregate entstehen dabei jedoch nicht in allen Fällen. Im Gegenteil, bei der Bildung von Makroaggregaten, die durch die Entstehung von Wasserstoffbindungen zwischen dem Polymer und dem Bodenteilchen begleitet wird, werden des öfteren keine Koagulationserscheinungen verzeichnet.

Bei Böden normaler Reihe werden die Makroaggregate von uns als Gebilde dritter Art betrachtet, die aus Mikroaggregaten bestehen. Die Grösse der Makroaggregate muss 0,05—0,1 mm und höher sein.

Eine wichtige Stelle in dem Gesamtproblem der Bodenstruktur nimmt die Frage über den höchsten Gehalt an Staubteilchen ein, die die Rolle der Makrostruktur nivellieren. Wiliams betrachtete diese Charakteristik als „Schädlichkeitsgrenze" und bestimmte sie als eine Größe, die 25—35% vom Bodengewicht beträgt.

Rewut und Pojassow haben festgestellt, daß sogar bei einem Zusatz von 57—58% Staub zum Bodengewicht, die Kapillarsteigung die Geschwindigkeit, die für eine Säule mit Teilchen 0,25 mm verzeichnet wurde, nicht erreicht.

Noch bemerkenswertere Erscheinungen werden bei der Ermittlung des Wasserdurchlässigkeitswertes beobachtet. So betrug die Wasserdurchlässigkeit für reine Aggregate von 2—3 mm 1620 mm pro Stunde; bei einem Zusatz von 30,7% Staub (< 0,25 mm) zum Bodengewicht betrug der entspre-

chende Wert 64 mm/Stunde, bei einem Staubzusatz von 50,7%—6 mm/Stunde und für den reinen Staub nur 0,8 mm/Stunde.

Die erzielten Ergebnisse erklären wir uns dadurch, daß sich im Boden ein Gerippe von wasserstabilen Mikroaggregaten bildet, selbst bei einem geringen Gehalt derselben, wodurch die Verdichtung des Bodens und die Herabsetzung der Größe der effektiven Poren begrenzt wird.

PHYSIKALISCHE VERHÄLTNISSE UND PROZESSE IM BODEN IN ABHÄNGIGKEIT VOM STRUKTURZUSTAND DESSELBEN

Das Grundlegende bei diesem Problem ist die Frage über den Aufbau, die Beschaffenheit und, letzten Endes über die Charakteristik des Porenraums des Bodens in Abhängigkeit von dessen struktureller Zusammensetzung.

Wir haben bereits drei Bodenkategorien je nach den vorherrschenden Aggregatgrössen festgelegt. Nun ist zu bemerken, dass falls im Boden nur primäre mechanische Elemente vorhanden sind, die Poren in solchem Boden ebenfalls sehr gleichmässig und von sehr geringen Abmessungen sind. Die Dichte eines derartigen Bodens kann 2,0 g/cm³ erreichen und die Porosität bis auf 25—26% vom Gesamtvolumen des Bodens herabgesetzt werden.

Die aus Mikroaggregaten gebildeten (mikrostrukturellen) Böden zeichnen sich durch das Vorhandensein von Poren zweierlei Grösse aus: sehr kleine Poren (zwischen den primären Teilchen) und grössere Poren (zwischen den Mikroaggregaten). Ein solcher Boden kann sich nur bis 1,6 g/cm³ verdichten, wobei seine Porosität nicht über die Grenze von 40—45% herabgesetzt wird.

Im makrostrukturellen Boden lassen sich Poren dreierlei Grösse feststellen (zwischen den Primärteilchen, zwischen den Mikroaggregaten, zwischen den Makroaggregaten); die Verdichtbarkeit dieses Bodens beträgt bis zu 1,1—1,2 g/cm³, und die höchste Porosität erreicht 60 Prozent und mehr.

Es ist weiter zu bemerken, dass schwere tonhaltige Schwarzerden, typische Grauerden und einige Arten von Salzböden als klassische Vertreter entsprechend von Makrostruktur-, Mikrostruktur- und strukturlosen Böden vorgestellt werden können. Dies zeigt ein umfangreiches Tatsachenmaterial über die mechanischen, Makrostruktur- und Mikrostruktur-Analysen dieser Böden.

Indem die Dichte der Schwarzerden gewöhnlich in den Grenzen von 1,0—1,2 g/cm³ schwankt, kann sie bei den Grauerden bis zu 1,45—1,60 g/cm³ ansteigen. In diesen weiten Grenzen (von 1,0 bis 1,6 g/cm³) finden die Dichten der Ackerschichten fast aller Mineralböden Raum. Für die absolute Mehrheit der landwirtschaftlichen Kulturen beträgt die optimale Dichte bei lehmigen und lehmsandigen Böden 1,0—1,25 g/cm³. Eine weitere Verdichtung führt zur Verschlechterung der physikalischen Verhältnisse im Boden und zur Herabsetzung des Ernteertrags. Insbesondere vergrössert sich stark mit fortschreitender Verdichtung die Anzahl der Poren im Boden, die einen Durchmeser unter 5μ aufweisen. Die Wasserdurchlässigkeit verringert sich, das Volumen, das mit für die Pflanzen verfügbarer Feuchtigkeit besetzt ist, steigt an.

Der Ernteertrag von landwirtschaftlichen Kulturen sinkt mitunter, infolge der Verdichtung der Böden mit feiner mechanischer Zusammensetzung, von 1,1 bis 1,6 g/cm^3 um das-2 bis 3-fache und noch stärker. Folglich bildet die Makrostruktur des Bodens den Regler für dessen Dichte und damit für die Fruchtbarkeit des Bodens.

Alle übrigen Vorzüge des Makrostruktur-Bodens dürfen wie folgt zusammengefasst werden:

1) Andere Belüftungsbedingungen, was man besonders deutlich beim Studium der Diffusionsprozesse von Gasen verfolgen kann.

Wenn bei beträchtlichem Befeuchten des Ausgangsbodens das Verhältnis D/D_0[1]) sich im Vergleich mit dem trockenen Boden um das dreifache verringert hat, so ist diese Grösse bei gut ausgesiebten Aggregaten, weniger als um das Doppelte zurückgegangen; beim Boden, der aus Aggregaten $<$ 0,25 mm besteht, erreichte der Abfall schon fast das Vierfache, und bei Aggregaten $<$ 0,1 mm sank diese Grösse schon mehr als um das 10-fache.

2) Andere Verteilung der Elemente des Wasserregimes und der Wasserbilanz in Böden, die verschiedene Strukturen aufweisen.

Die Untersuchung der stationaren Filtriergeschwindigkeit an Aggregaten aus gewöhnlicher lehmiger Schwarzerde mit einer Grösse von 1—2 mm und an einer Säule mit Aggregaten $<$ 0,25 mm hat im ersten Fall einen Wert von 0,43 mm/s und im zweiten Fall einen Wert von 0,002 mm/s gezeigt.

Der aus Mikroaggregaten gebildete Boden weist eine um 6 bis 8 mal grössere Geschwindigkeit und Höhe der Kapillarsteigung auf, als die reinen Makroaggregate.

Am zahlreichsten liegen gegenwärtig die Ergebnisse über vergleichende Untersuchung der Verdunstungsgeschwindigkeit der Bodenfeuchtigkeit in strukturellen Böden vor.
Wir wollen hier nur die wichtigsten Aspekte dieser Frage erläutern.

Es ist von altersher bekannt, dass der Austrocknungsverlauf von überfeuchtetem Boden durch gebrochene Kurven wiedergegeben wird. Man musste mindestens drei Strecken dieser gebrochenen Kurven beachten:

Das Verdunstungsgebiet, das durch die Linie beschrieben wird, die parallel zur Abszisse verläuft. In dieser Zone hängt die Verdunstung lediglich von äusseren Bedingungen ab, und die Struktur hat hier keine Bedeutung.

Die zweite Zone wird durch abfallende Verdunstungsgeschwindigkeit und ganz deutliche Abhängigkeit vom Bodenfeuchtigkeitsniveau gekennzeichnet. Sie beginnt bei der Feuchtigkeit, die 60—70% beträgt, und endet bei 30—40% der Wasserkapazität. Gerade dieser Bereich der Bodenbefeuchtung ist für das Leben der Pflanzen am wichtigsten. In diesem Fall verdunstet der Strukturboden weniger Wasser.

Die dritte Zone der Kurve wird durch einen niedrigen Stand der Verdunstung gekennzeichnet und bezieht sich auf den Bereich vom Kapillarbruch bis zur Feuchtigkeit, die dem ständigen Verwelken der Pflanzen entspricht.

[1]) D_0 — Diffusionskoeffizient in der Aussenluft; D — Diffusionskoeffizient im Boden.

Die Art der Austrocknung des Makrostruktur, Mikrostruktur- und des strukturlosen Bodens ist von Rode, Abramova, Bolschakow und Orjeschkina besonders eingehend erforscht worden.

Diese Forscher haben ermittelt, dass eine aus mikrostrukturellen Fraktionen bestehende Säule 35% des gesamten Wasservorrats, bezw. 48% des Ausgangsvorrats des verfügbaren Wassers in der Säule verliert. Dasselbe Bild wurde auch an natürlichem Erdboden aus Grauerde beobachtet, in dem Mikroaggregate dominieren. Im Boden, der aus Makroaggregaten besteht, verläuft der Austroknungsprozess dagegen ganz anders: bis zu 90% des gesamten Wassergehalts bei Feld-Kapazität und über 85% des verfügbaren Wassers ist nicht fähig, sich in flüssiger Phase zur Verdunstungsoberfläche zu bewegen und bleibt folglich länger im Boden erhalten.

Die Verdunstungsprozesse von Wasser aus einem verhältnismässig trokkenen Boden wurden durch Burow eingehend untersucht. Der Verfasser hat gezeigt, dass, falls kein Wind vorhanden ist, die feinen Fraktionen (1,0 und 0,25 mm) mehr verdunsten lassen als die 2—3 mm-Fraktionen. Bei starkem Wind verändert sich jedoch das Bild. Der Boden, der aus 2—3 mm Fraktion besteht, verliert mehr Wasser durch Verdunstung, als die feineren Fraktionen. Derartige Ergebnisse sind in grosser Anzahl vorhanden.
Die Hauptergebnisse hat der Verfasser bei Studien über die Verdunstung in Gefässen erzielt, die auf einem Brachfeld, sowie zwischen den Saaten von Getreide, Mais und Kartoffelpflanzungen aufgestellt waren.

Die Ergebnisse von Burow bringen einen überzeugenden Bewei dafür, dass bei einer hohen Bodenfeuchtigkeit die Aggregate von 0,5 bis 3,0 mm dauernd weniger Wasser verdunsten lassen als der zerstäubte grossklümpige Boden. Der Effekt der Vegetationsdecke ist hier schwach ausgedrückt, da die Bodenoberfläche stets befeuchtet blieb.

THEORIE UND PRAXIS DER BILDUNG UND DER WIEDERHERSTELLUNG DER MAKROSTRUKTUR DES BODENS.

Am schwierigsten in theoretischer Hinsicht und am wichtigsten für die Praxis ist die Frage der Bildung und der Wiederherstellung der Makrostruktur des Bodens.

Man dürfte in der Literatur für Bodenkunde und Agronomie keine zweite Frage finden, die so gründlich und vielseitig erläutert wurde, wie das Thema: Gräser und Makrostruktur, Gräser und Fruchtbarkeit des Bodens.

Grundlegende Veränderungen in der Struktur und in der Beschaffenheit des Bodens bewirkt die Tätigkeit des Menschen und, vor allem, die mechanische Bodenbearbeitung. Diese Frage wurde mit grösster Ausführlichkeit durch zahlreiche Untersuchungen von Wilenski, Werschinin,

Ryshow, Katschinski, Zyganow, Schutschenkow und vielen anderen sowie von einer Reihe Verfasser aus anderen Ländern erörtert.

Dieser Aspekt der Strukturbildung ist theoretisch gut geklärt. Die Hauptgrundsätze dieser Theorie bestehen darin, dass für jeden Boden eine bestimmte Feuchtigkeit vorhanden ist, die der optimalen Strukturbildung entspricht, und bei der ein beliebiges Umrühren bezw. mechanische Einwirkungen auf den Boden unumgänglich zur Bildung von Aggregaten führt. Je feiner die Kornzusammensetzung des Bodens ist, umso höher liegt die Feuchtigkeit der optimalen Strukturbildung. Es ist ferner festgestellt worden, dass bei der optimalen Strukturbildung entsprechenden Feuchtigkeit die beste Verdichtung der Böden beobachtet wird. Dies lässt sich dadurch erklären, dass die Teilchen in diesem Feuchtigkeitsbereich soweit befeuchtet sind, dass der „Schmiereffekt" am besten ausgedrückt ist. Eine weitere Steigerung des Wassergehaltes führt zum Verkeilen der Teilchen, zur Herabsetzung der Bodendichte und zur Lockerung der Kontakte zwischen den Teilchen. Die Abhängigkeit der Verdichtbarkeit des Bodens von dessen Wassergehalt wird so exakt ausgedrückt, dass auf dieser Grundlage Methoden und Geräte entwickelt sind, die zur Bestimmung der Bodenfeuchtigkeit sowie für die Ermittlung der Feuchtigkeit für optimale Strukturbildung dienen. Die Bestimmung der Feuchtigkeit für optimale Strukturbildung gestattet es, an das objektive Erkennen der Bodenreife entsprechenden Feuchtigkeit näher heranzukommen.

Zum Schluss soll noch die sogenannte künstliche Strukturbildung erwähnt werden, — ein Kapitel, das durch die Forscher des Wissenschaftlichen Forschungsinstituts für Agrophysik (Leningrad) in den dreissiger Jahren entdeckt wurde, und gegenwärtig auf allen Kontinenten weite Anerkennung gefunden hat.

Das Wesen der künstlichen Strukturbildung besteht bekanntlich darin, dass Substanzen in den Boden eingeführt werden, die ihrer Natur nach als Vermittler zwischen den Mikroaggregaten und den Primärteilchen des Bodens dienen können — ein Klebstoff, der wasserbeständige Verbindungen gewährleistet. Die Entdeckung dieser Stoffe und die Festlegung einer Norm für die Einführung derselben, um einen Effekt zu erzielen, bilden an sich den Beweis für das umfassende Verständnis des Wesens der Strukturbildungsprozesse seitens des Forschers.

Trotzdem stellt die Idee der künstlichen Strukturbildung eine Reihe von Problemen zur weiteren Erforschung auf. Das erste von ihnen ist das der Schaffung von speziellen Boden-Polymeren-Strukturbildnern, die hocheffektiv, leicht erschwinglich, billig und in Bodenverhältnissen beständig sein sollen. Es dürfte die Annahme nicht ausgeschlossen sein, dass derartige Substanzen unter den organomineralischen oder reinmineralischen Polymeren gefunden werden sollten.

Aus dem in diesem Abschnitt Gesagten folgt, dass die Rüstkammer der Verfahren zur Bildung und Wiederherstellung der Makrostruktur des Bodens bedeutend umfangsreicher ist als es bis zur jüngsten Zeit geschienen hat.

ZUSAMMENFASSUNG

Es wird das Problem der Bodenstrukturbildung besprochen, und es wird gezeigt, dass die Strukturbildung aus zwei unabhängigen Prozessen besteht: der Mikro-und der Makroaggregatenbildung. Aus Berechnugen ist zu ersehen, dass die Grössen der Mikroaggregate nicht 100—200 μ überschreiten. Die Makrostruktur wird als regulierender Faktor eines grossen Komplexes von Bodenbedingungen — der Dichte, der Porenverteilung, der Wasser- und Gasdurchlässigkeit, der Verdunstungsgeschwindigkeit u.a. — betrachtet. Es wird hervorgehoben, dass das Wurzelsystem der Pflanzen, ebenso wie die zeitige Bodenbearbeitung und die Einbringung strukturbildender Polymere, kraftvolle Faktoren der Makrostrukturbildung sind.

SUMMARY

The problem of soil structure formation is discussed and presented as being composed of two independent processes: the micro-and the macro-aggregate formation. According to calculations, the sizes of micro-aggregates do not exceed 100—200 μ. The macro-structure is considered as the regulating factor of a great complex of soil conditions such as bulk density, pore distribution, water- and gas permeability, evaporation rate a.s.o. The plant root system, as well as tillage within the optimum period and the incorporation of soil conditioners are pointed out to be significant factors in macro-structure formation.

RÉSUMÉ

On discute le problème de la formation de la structure du sol et l'on démontre que celle-ci consiste en deux processus indépendants: la formation des microagrégats et la formation des macroagrégats. Il ressort des calculs, que la dimension des microagrégats ne dépasse pas 100—200 μ. La macrostructure est considérée comme facteur régulateur d'un grand complexe de conditions du sol:densité apparente, distribution des pores, perméabilité à l'eau et à l'air, vitesse d'évaporation etc. On relève que le système radiculaire des plantes, tout comme les façons culturelles exécutées en temps opportun et l'incorporation de polymères formateurs de la structure, constituent des facteurs puissants de la formation de la macrostructure.

SUR LES RELATIONS ENTRE LA STRUCTURE DU SOL ET SES CONSTANTES HYDROLOGIQUES

B. N. MITCHOURINE [1]

La découverte des principes d'où pourront résulter comme une conséquence logique tous les types naturels de la composition physique des sols et leurs fonctions par rapport au mouvement de l'eau, de l'air, de la chaleur et à la croissance des racines de plantes est le but final de la théorie de la structure du sol.

On a montré par voie expérimentale que les agrégats de sol apparaissent l'un de l'autre en diminuant successivement en ce qui concerne la densité, mais en augmentant en ce qui concerne la porosité. La question se pose s'il existe un principe général auquel le développement des structures de sol soit soumis. Nous répondons à cette question d'une manière affirmative.

La théorie physique de base est la thermodynamique. Nous devons répondre à la question ce qu'est la structure du sol du point de vue de la thermodynamique.

En se basant sur la deuxième loi de la thermodynamique on peut supposer que les particules élémentaires, aussi bien que leurs agrégats sont compaquetés dans les sols dans un système proche de celui hexagonal (Mitchourine, 1957, 1962; Rodé, 1952). On peut exprimer cette hypothèse sous une forme mathématique simple si on considère comme critérium de la structure de sol le rapport des densités des particules élémentaires et de leurs agrégats (1):

$$\frac{D_1}{d}=\frac{D_2}{D_1}=\frac{D_3}{D_2}=\frac{D_n}{D_{n-1}}=0{,}74=\text{const}, \tag{1}$$

où d — le poids spécifique, D_1, D_2, D_3 et D_n la densité moyenne des systèmes à empaquetage du premier, deuxième, troisième et n-ème ordre des particules élémentaires. Le coefficient 0,74 caractérise la distribution hexagonale des particules élémentaires aussi bien que de leurs agrégats. Si les dimensions des particules de sol sont connues, alors le principe de leur empaquetage hexagonal à plusieurs ordres, en rapport avec le principe de la capillarité (2)

$$H_z=\frac{2\sigma}{r}, \tag{2}$$

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où H_r est la pression capillaire et σ la tension superficielle de l'eau, permet de calculer par voie théorique la porosité générale, la porosité sommaire des agrégats la porosité intérieure des agrégats aussi bien que leurs constantes hydrologiques. Le calcul de ces valeurs dans le domaine du poids volumétrique de 1,1 g/cm³ à 1,5 g/cm³ a permis d'établir un nombre de régularités.

1. La porosité sommaire des agrégats est une constante et est égale à 33% du volume total du sol (3)

$$\Sigma Pa = \frac{Pa}{Da} \cdot D = 0{,}33 = \text{const}, \tag{3}$$

où ΣPa est la porosité sommaire des agrégats, Pa — la porosité des agrégats individuels, Da — la densité des agrégats individuels, D — la densité générale du système.

La preuve : il résulte de l'équation 1

$$D_1 = 0{,}74\ d;\quad D_2 = (0{,}74)^2\ d;\quad D_3 = (0{,}74)^3\ d.$$

En supposant $d = 2{,}7$ g/cm³ et en utilisant ces formules nous trouvons :

$$D_1 = 2\ \text{g/cm}^3;\quad D_2 = 1{,}48\ \text{g/cm}^3;\quad D_3 = 1{,}1\ \text{g/cm}^3.$$

En utilisant la formule pour le calcul de la porosité générale nous trouvons : $P_1 = 0{,}26$; $P_2 = 0{,}45$ et $P_3 = 0{,}59$ où P_1, P_2 et P_3 — sont les porosités générales pour les empaquetages du premièr, deuxième et troisième ordres des particules du sol. En utilisant la formule (3) pour l'empaquetage du deuxième ordre nous trouvons

$$\Sigma Pa_2 = \frac{P_1}{D_1} \cdot D_2 = 0{,}33$$

et pour l'empaquetage du troisième ordre :

$$\Sigma Pa_3 = \frac{P_2}{D_2} \cdot D_3 = 0{,}33.$$

2. Si on suppose que la capacité au champ exprimée en % de volume du sol est égale à la porosité des agrégats (4) :

$$WcD = \Sigma Pa, \tag{4}$$

où Wc est la capacité au champ en % du poids et D — la densité générale du sol, alors la capacité au champ est aussi une constante et se trouve en dépendance inverse de la densité du sol (5) :

$$Wc_1 \cdot D_1 = Wc_2 \cdot D_2 = 0{,}33 = \text{const}. \tag{5}$$

Cette conséquence logique du principe de la structure de sol s'avère par les expériences faites par Tjouremnov (1923), Katchinski (1947), Rodé (1952), Mitchourine (1957) et d'autres, qui ont découvert que le produit de la capacité au champ par le poids volumétrique pour la plupart des types zonaux des sols (chernozems, sols châtains, sols gris forestiers,

sols derno-podzoliques limoneux), est une constante et qu'elle est voisine à 30—35% du volume total.

3. L'humidité au point de flétrissement permanent (% du volume) égale la porosité sommaire des microagrégats et se trouve en dépendance directe de la teneur en particules colloïdales.

L'humidité accessible aux plantes est égale à la différence entre la capacité au champ et le point de flétrissement. La porosité d'aération est égale à la différence entre la porosité totale et la porosité des agrégats.

Tableau 1

Dépendance des propriétés physiques et hidrologiques des sols de leur densité

Propriétés	Symboles	Densité g/cm³ (D)										
		1,0	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,0
Poids spécifique	d	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7
Porosité totale (%)	P	63	59	56	52	48	45	41	37	33	30	26
Produit de la porosité par la densité	PD	63	65	67	67	67	67	66	63	59	57	52
Porosité sommaire, des agregats (%)	ΣPa	32	33	33	33	33	33	33	33	30	28	26
Capacité en eau au champ (% du volume)	WcD	32	33	33	33	33	33	33	33	30	28	26
Humidité de la rupture des liens capillaires, entre les macroagrégats (% du volume)	WrC_1	38	39	39	39	39	39	39	—	—	—	—
Humidité de la rupture des liens capillaires entre les microagrégats (% du volume)	WrC_2	22	24	25	25	26	26	—	—	—	—	—
Point de flétrissement (% du volume)	WfD	13	14	16	17	19	20	21	22	23	25	26
Pores d'aération à la capacité au champ (% du volume)	$P_{aér}$	23	19	15	12	8	4	0	—	—	—	—
Humidité accessible aux plantes à la capacité au champ (% du volume)	W_{ac}	19	19	17	16	14	13	12	11	7	3	0
a) facilement accessible (% du volume)	$W_{facc}D$	10	9	8	8	7	7	6	6	0	0	0
b) difficilement accessible (% du volume)	$W_{dacc}D$	9	10	9	8	7	6	6	5	7	3	0

4. Lors d'une densité (un poids volumétrique) des sols plus grande que 1,3 g/cm³ la porosité d'aération devient insuffisante (moins de 12%) et lors d'une densité de moins de 1,1 g/cm³ — la porosité d'aération devient excessive (plus de 26%) pour la plupart des plantes.

Dans le domaine de densité situées entre 1,1 et 1,3 g/cm³ les régimes de l'eau et de l'air sont optima, les plantes épanouissant toutes leurs possibilités potentielles en ce qui concerne la croissance, le développement et le rendement (tableau 1).

5. La dimension des agrégats n'est pas un critérium suffisant pour l'estimation agronomique de la structure des sols, car une importance essentielle est attribuée au degré d'empaquetage des particules du sol, déterminé par la composition des bases absorbées, par la teneur en colloïdes et parcelle en humus.

La théorie et l'expérience montrent qu'un changement des dimensions des agrégats de 5 mm à 0,1 mm n'influence pas considérablement la capacité de rétention de l'eau, mais change considérablement la porosité d'aération.

CONCLUSIONS

Toutes nos connaissances dans le domaine de la physique des sols représentent la connaissance des structures du sol et de leurs fonctions, dont la diversité peut être expliquée comme la conséquence et principe de l'empaquetage hexagonal à plusieurs ordres des particules de sol et du principe de la capillarité.

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RÉSUMÉ

Un modèle géométrique du sol est proposé, la structure du sol y étant représentée par un empaquetage hexagonal à plusieurs ordres de sphères de différentes dimensions. Ce modèle conduit à une expression simple de la structure du sol en fonction de la densité des particules et des systèmes qu'elles composent. Cette expression en combinaison avec l'équation de Laplace-Jurin permet de donner la description complète des types fondamentaux des structures de sols et de déduire des formules pour le calcul de la porosité différentielle et des constantes hydrologique des sols. En partant des formules obtenues on peut, pour des rayons et densités donnés des particules primaires et de leurs agrégats, présenter sous forme de tableau les variations absolues de la porosité différentielle et des constantes hydrologiques des sols en fonction de la densité totale de ces derniers.

SUMMARY

A geometrical soil model is proposed, its structure being represented by a hexagonal multi-stage packing of spheres of different sizes. This model leads to a simple expression of the soil structure, depending on particle density and on the systems these particles build. This expression, combined with the Laplace-Jurin equation, allows a complete description of basic soil structure types and the derivation of formules for calculating the differential porosity and the soil moisture constants. Proceeding from these formulas and for given diameters and densities of the elementary particles and of their aggregates, tables are obtained for values of the differential porosity and of the soil moisture constants for different soil densities.

ZUSAMMENFASSUNG

Es wird ein geometrisches Bodenmodell vorgeschlagen, bei dem die Bodenstruktur durch eine mehrstaffelige hexagonale Einpackung von Sphären verschiedener Grösse dargestellt ist. Dieses Modell führt zu einem einfachen Ausdruck der Bodenstruktur in Abhängigkeit von der Teilchendichte und den Systemen, die sie bilden. Dieser Ausdruck, mit der Laplace-Jurin-Gleichung in Verbindung gebracht, ermöglicht die vollständige Beschreibung der Bodenstruktur-Grundtypen, und Formeln für die Berechnung der differentiellen Porosität und der hydrologischen Konstanten herzuleiten. Von den erhaltenen Formeln ausgehend, vermag man für gegebene Radien und Dichten der Elementarteilchen und ihrer Aggregate die absoluten Schwankungen der differentiellen Porosität und der hydrologischen Konstanten der Böden in Abhängigkeit von der Gesamtdichte der letzteren in Tabellenform darzustellen.

ÜBER DIE NACHTEILE EINER BODENTROCKNUNG IM LABOR AUF DIE BESTIMMUNG DER WASSERBESTÄNDIGEN KRÜMELANTEILE

A. KULLMANN [1]

Bei Untersuchungen von Bodenproben im naturfeuchten Zustand zeigt sich (Kullmann, 1962), dass auf den von uns ausgewählten Versuchsflächen mit zunehmender Bodenfeuchtigkeit der Anteil wasserstabiler Krümel—von einer Ausnahme abgesehen — abnimmt. Für die Eliminierung dieses Einflusses spricht:

a) wenn die im Laufe der Zeit zu beobachtenden Veränderungen im Anteil wasserstabiler Krümel betrachtet werden sollen, müssten Werte zugrunde liegen, die unabhängig von dem Einfluss durch den jeweiligen Feuchtigkeitsgehalt bei der Probenentnahme sind. Nur dann könnte eine Zunahme oder Minderung stabiler Krümelanteile in Untersuchungszeiträumen konstatiert werden bzw. Betrachtungen über die Veränderungen hervorrufenden Ursachen (soweit sie nicht den Feuchtigkeitseinfluss betreffen) angestellt werden;

b) bei Gegenüberstellung des Einflusses verschiedener Versuchsvarianten auf die stabilen Krümelanteile, bei denen eine dynamische Betrachtung von untergeordnetem Interesse ist, stören Unterschiede im Feuchtigkeitsgehalt der Proben.

Dieser Feuchtigkeitseinfluss liesse sich am einfachsten für a) umgehen, wenn die Proben nur bei gleicher Bodenfeuchtigkeit entnommen und untersucht werden. Doch erweist sich diese Verfahrensweise bei dynamischer Problemstellung als ungeeignet, da infolge stetiger Schwankungen im Witterungsablauf die Probenentnahmen nicht in äquidistanten kurzen Zeitintervallen (Kullmann, 1962) durchgeführt werden können.

Dieser Feuchtigkeitseinfluss kann aber eliminiert werden, wenn nach Berechnung der Regression für die Abhängigkeit der im naturfeuchten Zustand ermittelten Krümelanteile von der Bodenfeuchtigkeit die einzelnen Messwerte unter Heranziehung des Regressionskoeffizienten auf einen Feuchtigkeitsgehalt, der dem lufttrockenen Zustand des Bodens entspricht, umgerechnet werden. Werden diese korrigierten Messwerte dann wiederum gegen den Feuchtigkeitsgehalt bei der Probenentnahme aufgetragen, dann wird eine durch die Punktwolke gelegte Gerade parallel zur Abszisse verlaufen.

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Infolge der Eliminierung des Feuchtigkeitseinflusses ist also diese letztere Gerade gegenüber der Regressionsgeraden aufgerichtet worden, wobei der „Drehpunkt" für diese Aufrichtung der Geraden in einem Feuchtigkeitsbereich liegt, der dem lufttrockenen Zustand des Bodens entspricht.

Dieser erhöhte Arbeitsaufwand, Berechnung der Regression und Umrechnung eines jeden einzelnen Messwertes auf einen bestimmten Feuchtigkeitsgehalt, müsste sich umgehen lassen, wenn jede einzelne Bodenprobe vor der Untersuchung auf ihre stabilen Krümelanteile stets auf einen annähernd gleichen Feuchtigkeitsgehalt getrocknet würde. Diese Verfahrensweise ist sowieso bei den weitaus meisten, in der Literatur beschriebenen Verfahren, üblich. Ausserdem muss bei Anwendung einiger Methoden zur Krümelstabilitätsmessung vorausgesetzt werden, dass durch Trockensiebung gewonnene Messaggregatfraktionen für die Stabilitätsmessung vorliegen, wofür eine Trocknung der Bodenproben vor der Aussiebung erforderlich ist.

Wenn nun die Krümelanteile — gleichgültig ob sie im Freiland abtrocknen oder unter den im Labor vorliegenden Gegebenheiten — den gleichen Kräften ausgesetzt und durch diese in gleicher Weise verändert werden, ist gegen eine Trocknung des Bodens im Labor nichts einzuwenden, falls folgende Bedingung erfüllt ist: Werden die Resultate der zuvor getrockneten Proben gegen den Feuchtigkeitsgehalt bei der Probenentnahme aufgetragen, so müsste wiederum eine durch die Messwerte gelegte Gerade parallel zur Abszisse verlaufen, wie das bereits für die mathematisch vom Feuchtigkeitseinfluss bereinigten Werte dargelegt worden ist.

BESCHREIBUNG DER VERSUCHSFLÄCHEN UND ANGEWENDETEN METHODEN

Von einem sandigen Lehmboden (zur Bodencharakteristik siehe Tabelle 1) mit sechsjährigem Wiesenbestand wurden in achttägigen Abständen zu 35 Terminen Bodenproben aus 0—10 cm und 10—20 cm Tiefe entnommen. In 5 Wiederholungen wurde der Feuchtigkeitsgehalt und der Anteil wasserstabiler Krümel nach dem Schallwäscher- und Tauchverfahren (Kullmann, 1962) einmal für die Proben im naturfeuchten Zustand und zum anderen nach Trocknung des Bodens bestimmt. Diese Trocknung bis auf einen Boden-crd.

Tabelle 1

Zur Bodencharakteristik

Bodenart	Bodentyp	Ton < 0,002 mm	Schluff 0,002—0,02 mm	Hygroskopizität nach Mitscherlich	T-Wert n. Mehlich	pH-Wert (n/10KCl)	C-Gehalt n. Rauterberg-Kremkus
sandiger Lehm	verbraunter Lessivé	16%	10%	1,5%	8,2 mval.	6,3	0,75%
schwerer Lehm	Braunerde	22%	35%	3,8%	15,3mval.	6,6	1,11%

feuchtigkeitsgehalt, der etwa der halben Hygroskopizität nach Mitscherlich entspricht, erfolgte innerhalb 90 Std., wobei je nach dem Feuchtigkeitsgehalt bei der Probenentnahme der Trocknungsprozess bei 40°C im Trockenschrank beschleunigt wurde.

VERSUCHSERGEBNISSE

Für den Zusammenhang zwischen Krümelanteil und Bodenfeuchtigkeitsgehalt bei der Probenentnahme [1] sind die Regressionskoeffizienten in Tabelle 2 berechnet und die entsprechenden Geraden in Abbildung 1 dargestellt worden. Hieraus geht hervor, dass in jedem Fall die Krümel der im naturfeuchten Zustand untersuchten Proben signifikant mit zunehmendem Feuchtigkeitsgehalt abnehmen. Durch Trocknung des Bodens vor der Stabilitätsmessung wird jedoch nur in 10—20 cm Tiefe ein nicht signifikant von Null verschiedener Regressionskoeffizient ermittelt; doch bleibt diese Gerade um 4,4% unter dem zu erwartenden Verlauf, so dass nicht von einer Eliminierung des Feuchtigkeitseinflusses im erwarteten Sinne gesprochen werden kann. Die Ergebnisse der anderen beiden Versuchsanstellungen haben signifikant positive Regressionskoeffizienten erbracht; der Feuchtigkeitseinfluss wird also ebenfalls nicht eliminiert, er schlägt sogar von einem negativen in einen positiven Zusammenhang um, wodurch eine Verzerrung der Werte bedingt wird. Ähnliche Resultate sind auf der gleichen Versuchsfläche im darauffolgenden Jahr sowie im gleichen Jahr auf anderen Flächen erzielt worden (teilweise bleibt auch die negative Korrelation erhalten, teilweise ist auch ein kurvilinearer Zusammenhang nachzuweisen gewesen). Nur in < 10% aller hierauf betrachteter Versuchsserien, die hier nicht alle im einzelnen angeführt werden können, ist eine Eliminierung des Feuchtigkeitseinflusses durch Trocknung des Bodens möglich gewesen. Dieses Verhalten der getrockneten Bodenproben wird nur unwesentlich beeinflusst, wenn die Proben von der Stabilitätsanalyse noch durch Trockensiebung fraktioniert werden.

Tabelle 2

Regressionskoeffizienten

Verfahrensweise	Schallwäscherverfahren 0—10 cm	Tauchverfahren 0—10 cm	Tauchverfahren 10—20 cm
naturfeucht	—0,846*	—0,634*	—1,244***
getrocknet	0,485*	0,758**	—0,014⁻

Signifikanzzeichen (Mudra/1958): * gesichert; ** gut gesichert; *** sehr gut gesichert; — nicht gesichert

[1] Die entsprechenden Regressionskoeffizienten für die Abhängigkeit der Krümelanteile von den Bodenfeuchtigkeitsgehalten nach der Trocknung des Bodens sind nicht signifikant von Null verschieden.

Werden nun die mit dem Tauchverfahren ermittelten Messwerte (0—10 cm Tiefe), die für Abbildung 1 zugrunde gelegt worden sind, in Abhängigkeit von der Zeit aufgetragen, ergibt sich der in Abbildung 2 dargestellte Kurvenverlauf. Die Kurve für die im naturfeuchten Zustand untersuchten Proben weist einen bewegten Kurvenverlauf während des Untersuchungszeitraumes sowie Perioden mit deutlichen Minima und Maxima auf. Die negative Korrelation zur Bodenfeuchtigkeit ist unverkennbar; ausgenommen ist das Verhalten im Spätherbst, wo ein Saisoneinfluss zum Ausdruck kommt (Kullmann, 1962). Die Kurve für die mathematisch vom Feuchtigkeitseinfluss eliminierten Messwerte zeigt keinen wesentlich anderen Verlauf. Deutlich treten dagegen die Abweichungen hervor, wenn vergleichend die Kurve für die zuvor getrockneten Proben betrachtet wird. Die Differenzen zwischen den mathematisch vom Feuchtigkeitseinfluss eliminierten Werten und den Resultaten der zuvor getrockneten Proben variieren in signifikantem Ausmass im Verlaufe der Untersuchungsperiode.

Entsprechende Aussagen treffen auch für die Ergebnisse anderer Versuchsanstellungen zu.

Abschliessend verbleibt noch zu betrachten, wie die Rangordnung gegenübergestellter Versuchsvarianten durch die Trocknung der Proben verändert werden.

Von einem schweren Lehmboden (Tabelle 1) wurden 1961 wöchentlich zweimal zu insgesamt 25 Untersuchungsterminen aus 0—20 cm Tiefe Proben entnommen und diese teils im naturfeuchten Zustand und teils nach Trocknung des Bodens auf ihre Anteile wasserstabiler Krümel nach dem Tauchverfahren analysiert. Gegenübergestellt wurden die Ergebnisse der Fruchtfolge I (1959 Kleegras, 1960 Kartoffeln, 1961 Winterweizen mit Untersaat) mit denen der Fruchtfolge III (1959 Hafer, 1960 Kartoffeln, 1961 Winterweizen). Die mittleren Differenzen zwischen beiden Varianten sind in Tabelle 3 wiedergegeben, desgleichen die Signifikanzen aus der varianzanalytischen Verrechnung.

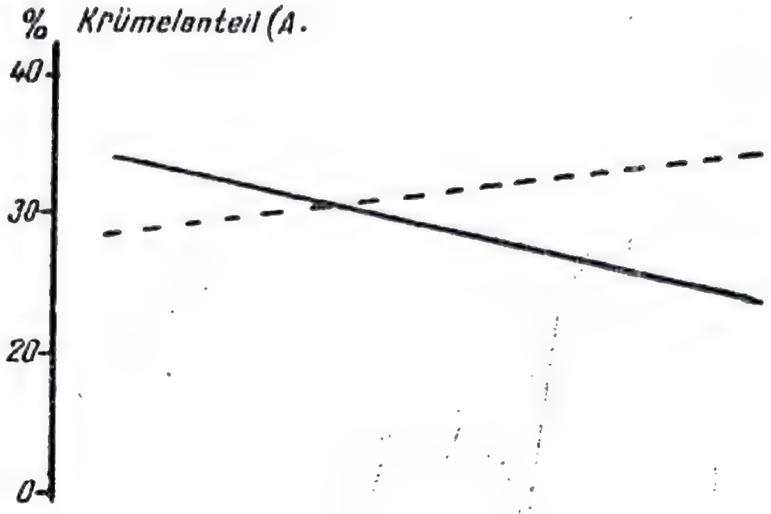
Tabelle 3

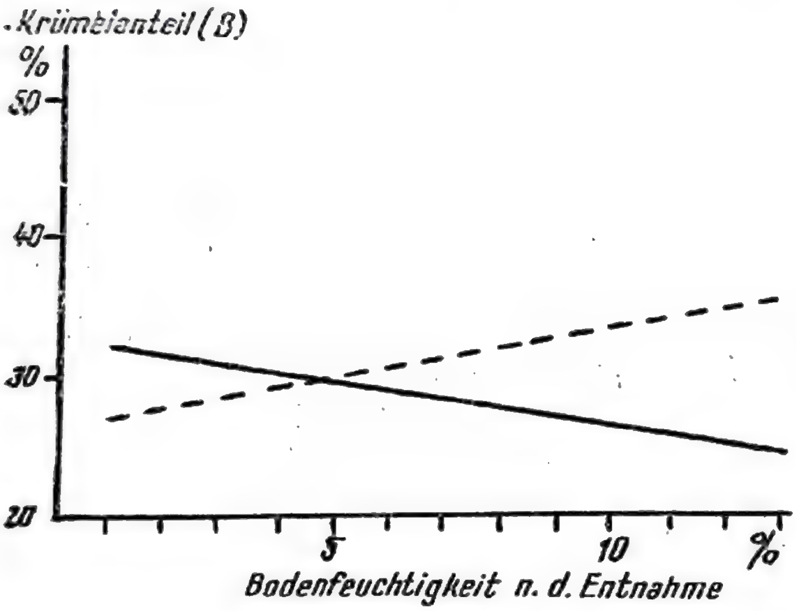
Differenzen (d) zwischen den beiden Fruchtfolgevarianten

Im naturfeuchten Zustand untersucht		Feuchtigkeitseinfluss mathematisch eliminiert		Im getrockneten Zustand untersucht	
d	Sich.	*d.*	Sich.	*d*	Sich.
—1,01	—	1,96	+	—0,81	+++

Die Ergebnisse der im naturfeuchten Zustand untersuchten Proben beider Fruchtfolgevarianten sind im Mittel über den Untersuchungszeitraum nicht signifikant verschieden. Erst nach mathematischer Eliminierung des Feuchtigkeitseinflusses wird eine signifikante Überlegenheit der Fruchtfolge III gegenüber Fruchtfolge I erkennbar.

Nach Trocknung des Bodens und anschliessender Analyse wird wohl auch eine signifikante Differenz ermittelt, doch ist hiernach Fruchtfolge III unter-





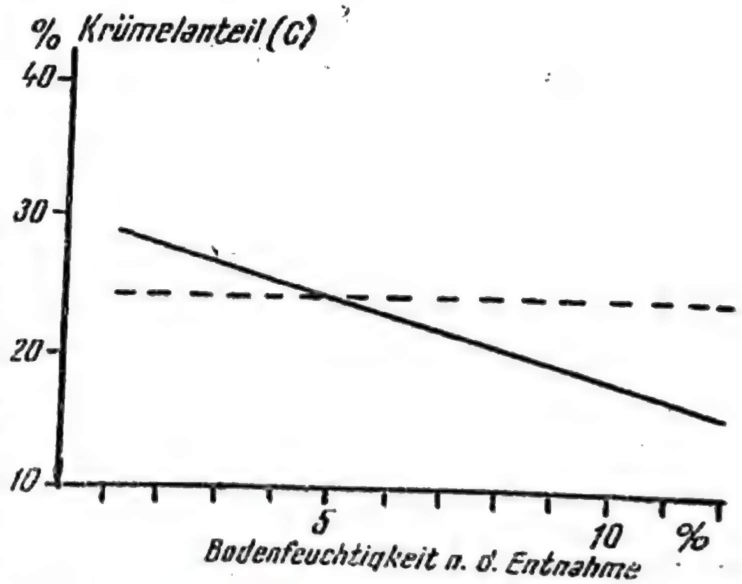


Abb. 1. Die Regressionsgeraden für die mit dem Schallwäscherverfahren (A) in 0—10 cm Tiefe sowie mit dem Tauchverfahren (B) in 0—10 cm Tiefe und (C) in 10—20 cm Tiefe ermittelten Krümelanteile (> 1 mm Äquiv.—Durchm.) in Abhängigkeit von der Bodenfeuchtigkeit nach der Entnahme

——— im naturfeuchten Zustand untersuchte Proben

– – – im trockenen Zustand untersuchte Proben.

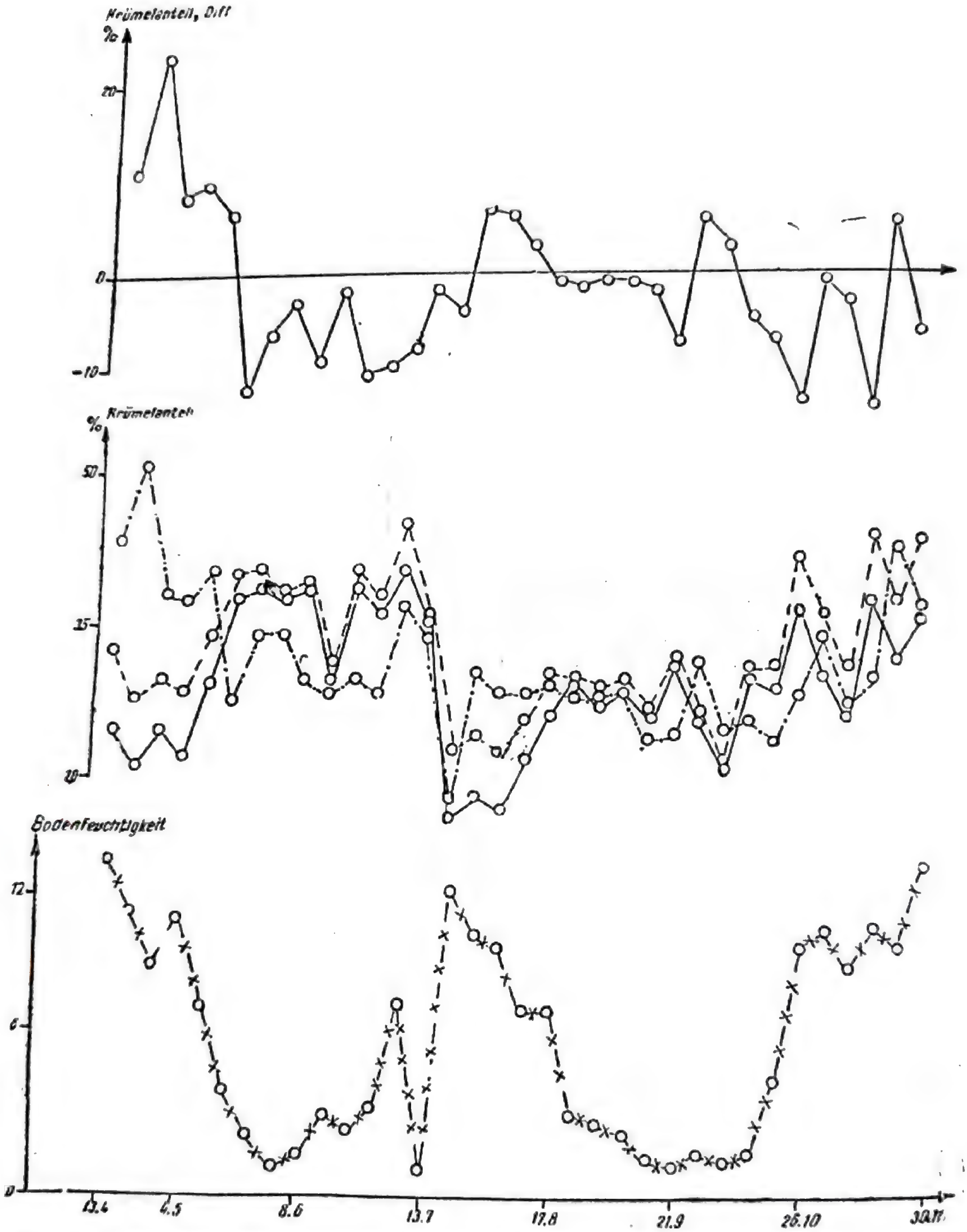


Abb. 2. Die mit dem Tauchverfahren ermittelten Krümelanteile (> 1 mm Äquiv.-Durchm.) sowie die Bodenfeuchtigkeiten nach der Entnahme (—x—x) in Abhängigkeit von der Zeit

———————(untere Kurve) Ergebnisse der im naturfeuchten Zustand untersuchten Proben;

– – – – – – Ergebnisse der im naturfeuchten Zustand untersuchten Proben sind auf den Wassergehalt (n. d. Trocknen) umgerechnet = y_{korr};

—·—·—· Ergebnisse der im trockenen Zustand untersuchten Proben;

———————(obere Kurve) Differenz der Krümelanteile zwischen den im getrockneten Zustand untersuchten Proben und den y_{korr}. -Werten.

legen. Die beiden Verfahrensweisen zur Eliminierung des Feuchtigkeitseinflusses führen also zu einer gegensätzlichen Rangordnung. Um nun zu prüfen, mit welcher Methode der Strukturzustand im Augenblick der Probenentnahme am treffendsten charakterisiert wird, haben wir die Ergebnisse der zuvor getrockneten Proben gegen den Feuchtigkeitsgehalt bei der Probenentnahme aufgetragen. Hierbei zeigt sich, dass der Feuchtigkeitseinfluss nicht eliminiert, d.h. die Regressionsgerade signifikant von Null verschieden ist. Ausserdem tritt ein Vorzeichenwechsel des Regressionskoeffizienten auf, wie er in ähnlicher Weise für einen anderen Boden bereits in den linken Darstellungen der Abb. 1 demonstriert ist. Demnach dürften nur die mathematisch vom Feuchtigkeitseinfluss bereinigten Werte das wahre Verhältnis zwischen den beiden Fruchtfolgegliedern zum Ausdruck bringen.

DISKUSSION

Anhand dieser Unterlagen kann also für die im Labor getrockneten Proben der von uns untersuchten Versuchsflächen nicht damit gerechnet werden, dass stets weder der Feuchtigkeitseinfluss in dem zu erwartenden Sinne eliminiert ist, noch die Relationen zwischen den Versuchsgliedern unverändert bleiben. Offensichtlich werden bei Trocknung des Bodens im Labor noch andere Kräfte als im Freiland wirksam, so dass mit derartig getrockneten Proben nicht mehr der im Augenblick der Probenentnahme vorliegende Strukturzustand erfasst werden kann. Sollte man jedoch eine Trocknung des Bodens — sei es zur Eliminierung des Bodenfeuchtigkeitseinflusses, sei es aus anderen Gründen — beibehalten wollen, müssten erst die Ursachen für das abweichende Verhalten der im Labor getrockneten Proben erforscht werden. Dann liessen sich eventuell auch methodisch die Möglichkeiten finden, mit getrockneten Bodenproben Wasserstabilitätsbestimmungen durchzuführen.

Aus den dargelegten Untersuchungen lässt sich nicht ableiten, welche unterschiedlichen Kräfte bei der Abtrocknung des Bodens im Freiland und im Labor auf die Wasserbeständigkeit der Krümel wirksam werden. Diese Kräfte scheinen offensichtlich in Abhängigkeit von dem Bodenfeuchtigkeitsgehalt bei der Probenentnahme zu variieren, wie die Ergebnisse beweisen. Darum dürften Versuchsanstellungen zum Studium des Zusammenhanges zwischen dem stabilen Krümelanteil und der Bodenfeuchtigkeit nicht genügen, wenn hierzu Proben nur einmalig vom Feld entnommen worden sind, anhand derer dann der Zusammenhang bei langsamer Abtrocknung (Sillanpää, 1959) oder schrittweiser Anfeuchtung (Koepf, 1959) charakterisiert werden soll.

Die Ursachen für diesen Trocknungseffekt im Labor müssen entweder in der Art und Weise der Trocknung (Temperatur, Geschwindigkeit, Lagerungsdauer, Methode) oder/und in der Art und Weise der Wiederbefeuchtung (Methode, Geschwindigkeit) zu suchen sein, die zwangsläufig mit der Messung der Krümelstabilität gegeben ist.

Werschinin (1958) weist beispielsweise daraufhin, dass bei der schnellen Abtrocknung im Labor nicht die Voraussetzungen „für die Kolloidbrücken

geschaffen werden, wie sie bei der langsamen Verdunstung des Wassers aus dem Boden im Gelatinierungsprozess der Kolloide zwischen den Bodenteilchen entstehen" Auch Dettmann (1958), Emerson (1959) u.a. verweisen auf den Einfluss der Orientierung der Kolloide bei der Krümelstabilisierung, die abhängig von der Geschwindigkeit der Abtrocknung ist, bzw. auf das Verhalten der Krümel in Abhängigkeit zum Orientierungsgrad bei der Wiederbefeuchtung des Bodens. Daneben dürften aber auch Polymerisationsvorgänge und Koagulation der Humate sowie zahlreiche andere physikalische, chemische und biologische Kräfte bei der Trocknung des Bodens im Labor in anderer Weise wirksam werden als im Freiland. Doch müssten für eine diesbezügliche Klärung noch spezielle Versuchsanstellungen vorgesehen werden.

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ZUSAMMENFASSUNG

Zu zahlreichen Terminen im Laufe der Vegetationsperiode sind von verschiedenen Versuchsflächen in mehreren Jahren Bodenproben entnommen und sofort im naturfeuchten Zustand nach mehreren Methoden auf ihre Anteile wasserstabiler Krümel untersucht worden. Der hierbei ermittelte Einfluss der Bodenfeuchtigkeit lässt sich mathematisch über Regressionsanalysen eliminieren. Eine Trocknung des Bodens auf annähernd gleiche Wassergehalte vor der Bestimmung des stabilen Krümelanteiles vermag kaum den Feuchtigkeitseinfluss zu eliminieren, ausserdem erscheinen die Messergebnisse mehr oder weniger verzerrt. Diese Nachteile wirken sich signifikant aus, wenn die Krümelanteile in Abhängigkeit von der Zeit bzw. von dem Einfluss zweier Fruchtfolgevarianten betrachtet werden. Demnach kann mit zuvor getrockneten Bodenproben nicht mit Sicherheit der im Augenblick der Probenentahme vorliegende Strukturzustand des Bodens charakterisiert werden.

SUMMARY

Soil samples were taken from different experimental plots at various times during the growth period over a number of years. Several methods were applied to investigate them immediately in their natural state of moisture in order to ascertain the water stable aggregate content. Regression analyses can be utilized to eliminate mathematically the hereby determined moisture influence. Soil drying to approximately equal water contents prior to the determination of the proportion the stable aggregate content is hardly able to eliminate the moisture influence. In addition, the resulting measurements seem to be more or less disturbed. These disad-

vantages have a significant effect if aggregate contents are considered as a function of time, under the influence of two crop rotations. Consequently previously dried soil samples cannot be used to characterize with any degree of certainty the structural state of the soil at the time of sampling.

RÉSUMÉ

Pendant plusieurs années, de nombreux échantillons de sol ont été prélevés dans différants champs d'expérience au cours de la période de végétation. Ils ont été examinés immédiatement, dans leur état d'humidité naturelle, selon plusieurs méthodes, afin de déterminer le taux des agrégats stables à l'eau. L'influence de l'humidité déterminée peut-être éliminée mathématiquement par des analyses de regression. Le séchage du sol à des degrés d'humidité approximativemment égaux avant la détermination du taux des agrégats stables, ne saurait faire disparaître l'influence de l'humidité. De plus, les résultats du mesurage apparaîssent plus ou moins déformés. Ces désavantages s'expriment d'une façon significative lorsque le taux des agrégats est considéré dans son dépendance par rapport au temps, ou encore par rapport à l'influence de deux variantes de rotation de cultures. Pour cette raison on ne peut déterminer avec certitude l'état structurel du sol au moment de l'échantillonnage soumettant les échantillons à un séchage préalable.

DISKUSSION

F. F. R. KOENIGS (Niederlande). Darf man erwarten, dass die Regressionsgleichung, die in der ersten Darstellung gezeigt wurde, auch für andere Böden angewandt werden kann?

A. KULLMANN. Auf einem sandigen Lehmboden und auf einem sandigen Tonboden wurden zahlreiche Versuche auf verschiedenen Flächen in mehreren Jahren durchgeführt. Stets zeigten die im naturfeuchten Zustand untersuchten Bodenproben eine negative Abhängigkeit der Krümelanteile vom Bodenfeuchtigkeitsgehalt. Ausgenommen sind die Resultate während der Wintermonate, wo keine Abhängigkeit vorliegt. Auf einem schweren Lehmboden dagegen wurde ein positiver Zusammenhang gefunden. Dieser Zusammenhang könnte eventuell ein parabelförmiger sein (siehe Gliemeroth 1949), aber unsere Probenentnahme erfolgte nur während einer anhaltend feuchten Witterung.

L. L. DE LEENHEER (Belgien). Mit Rücksicht auf die Nachteile der Bodentrocknung möchte ich fragen, welcher, Ihrer Meinung nach, der günstigste Ausgangspunkt bei der Krümelanalyse ist, in der Weise, dass dieser Ausgangszustand genau reproduziert ist.

A. KULLMANN. Je nach dem Untersuchungsziel müssen die Methoden variieren. Wir interessieren uns für die Dynamik der Stabilitätseigenschaft und müssen deshalb die Proben im naturfeuchten Zustand untersuchen. Ausserdem wenden wir parallel mehrere Verfahren an, um einmal den gesamten Krümelanteil zu erfassen und andere Gruppen unterschiedlichen Stabilitätsgrades (durch Variation der mechanischen Beanspruchung während der Wassereinwirkung). Das Verfahren nach Van Bavel, auf das Sie zurückgreifen, ist deshalb nicht anwendbar. Ausserdem wird durch eine Trockensiebung vor der Stabilitätsmessung möglicherweise ein tiefgreifender Einfluss auf die Resultate der Stabilitätsanalyse ausgeübt.

ASPECTS DE LA CARACTÉRISATION QUANTITATIVE DE LA MICROSTRUCTURE DES SOLS

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Le caractère complexe et la diversité des facteurs qui contribuent à la formation de la structure des sols a constitué le sujet de nombreux articles dans la littérature et a formé le thème des discussions dans les réunions internationales (De Boodt, 1960; Kullmann, 1958). Les résultates obtenus ces derniers temps (Alderfer et Merkle, 1941; Kolochkova, 1960; Pannaboke et Quirk, 1957; Popovăţ, 1934; Puri et Rai, 1944; Teodoru et Moţoc, 1962, 1963; Tiouline, 1954) ont confirmé l'opinion selon laquelle les microagrégats de moins de 0,25 mm auraient une influence négative sur les propriétés physiques des sols ; ils montrent que la composition des microagrégats a une grande importance s'ils sont formés de particules élémentaires ou représentent des agrégats constitués à leur tour de particules encore plus petites.

Les résultats publiés pas les divers auteurs sont différents parce que les méthodes d'analyses ne sont pas les mêmes ; cela est dû au différents degrés de dispersion réalisés, au temps de la sédimentation et à la profondeur à laquelle on prend la suspension, qui sont aussi différents (Astapov, 1958; Godline, 1953; Middleton et al., 1932). La comparaison des résultats est rendue une fois de plus difficile à cause de l'inexistence d'un système unitaire d'interprétation, auquel on ajoute l'absence d'un nombre assez grand d'analyses de toutes les variétés de sols.

Dans cet article on caractérise l'état microstructural des sols par rapport à leur teneur en microagrégats, on présente le facteur de dispersion pour les principaux types de sols et on établit les coefficients de corrélation entre les valeurs obtenues par analyses microstructurales et granulométriques.

LA MÉTHODE DE TRAVAIL

On caractérise la microstructure des sols conformément aux résultats des analyses microstructurales et granulométriques des échantillons prélevés de 127 profils représentant des sols de steppe, de sylvosteppe et de

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forêt. Pour chaque type de sol ont été analysés 15 profils. L'analyse microstructurale et la préparation des échantillons pour l'analyse granulométrique ont été faites selon la méthode Katchinski (1958). La composition granulométrique a été déterminée par la méthode de la pipette. Les résultats obtenus ont été récalculés sous la forme de la moyenne arithmétique ($\bar{x}$) accompagnée par l'erreur de la moyenne ($s\bar{x}$), ainsi que sous celle des différences entre les deux sortes d'analyses et leur degré de signification (Săulescu, 1959; Snedecor, 1957).

LES RÉSULTATS OBTENUS

Les résultats obtenus par l'analyse microstructurale indiquent une rédistribution variable des fractions, caractéristique pour tous les types de sols étudiés (tabl. 1). Selon Alderfer et Merkle (1941) à l'analyse microstructurale on obtient pour les grandes fractions une teneur plus élevée qu'à l'analyse

Tableau

Résultats de l'analyse microstructurale et granulométrique,

Type de sol	Horizon	Teneur en fractions			
		2—0,2 mm		0,2—0,02 mm	
		x	d	x	d
Chernozems châtains de steppe	A_a	0,36 / 1,39	+1,03**	56,37 / 68,28	+11,91**
	A_n	0,44 / 1,99	+1,55**	55,04 / 67,12	+12,08**
Chernozems châtains	A_a	0,36 / 2,44	+2,08***	45,41 / 59,47	+14,06***
	A_n	0,32 / 3,52	+3,22***	44,08 / 55,52	+10,94***
Chernozems chocolat	A_a	0,50 / 1,31	+0,81*	43,57 / 59,72	+16,15***
	A_n	0,51 / 1,99	+1,48***	43,02 / 56,88	+13,86***
Chernozems peu lévigués	A_a	0,40 / 1,51	+0,91***	43,74 / 57,73	+13,99***
	A_n	0,39 / 1,92	+1,53**	41,62 / 56,27	+14,65***

granulométrique ; en même temps on constate une teneur moins élevée pour les petites fractions. La composition microstructurale peut donc être caractérisée differentiellement par la teneur procentuelle en fractions microstructurales. Ceci constitue en même temps une indication qualitative, parce qu'elle indique la stabilité hydrique des microagrégats. Les différences entre les deux séries d'analyses nous donnent encore des indications sur le rôle joué par les particules élémentaires dans la constitution des microagrégats.

Pour les sols de steppe limoneux formés sur loess on a obtenu à l'analyse microstructurale des valeurs plus élevées qu'à l'analyse granulométrique en ce qui concerne les fractions plus grandes que 2μ ; au contraire, les valeurs sont moins élevées pour les fractions plus petites que 2μ ; la teneur en fractions microstructurales grossières diminue de 70% — pour les sols châtains de steppe — à 61% pour les chernozems chocolat, mais elle croît dans le même sens de 26% à 34% pour les fractions microstructurales moyennes. Les différences entre les deux séries d'analyses sont en général significatives. La croissance de la teneur en ces fractions à l'analyse microstructurale est determinée

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leurs différences et la signification de celles-ci

microstructurales (au dénominateur) et granulométriques (au numérateur)(%)								K_x
0,02—0,01 mm		0,01—0,02 mm		0,002—0,001 mm		<0,001 mm		
x	d	x	d	x	d	x	d	
13,18 / 14,0	+0,82	9,28 / 12,42	+3,14**	2,89 / 2,06	—0,83	17,92 / 1,85	—16,07°°°	10,32
14,46 / 14,51	+0,05	9,12 / 12,00	+2,88	3,05 / 2,07	—0,98	17,89 / 2,31	—15,58°°°	12,91
14,92 / 18,63	+3,71**	11,32 / 15,52	+4,20***	2,96 / 2,18	—0,78°	25,03 / 1,76	—23,27°°°	7,03
14,62 / 18,20	+3,58**	12,48 / 16,77	+4,29***	3,86 / 3,17	—0,69	24,64 / 2,82	—21,82°°°	11,44
14,53 / 16,87	+2,34*	10,69 / 16,82	+6,13***	4,20 / 3,02	—1,18	26,51 / 2,26	—24,25°°°	8,52
13,54 / 17,14	+3,60***	11,28 / 17,57	+6,29***	5,48 / 3,38	—2,10°	26,17 / 3,04	—23,13°°°	11,61
12,97 / 16,60	+3,63*	11,65 / 18,38	+6,73***	4,45 / 3,04	—1,41	26,79 / 2,94	—23,85°°°	10,97
13,15 / 15,39	+2,24	11,65 / 18,19	+6,54***	4,47 / 3,76	—0,71	28,72 / 4,49	—24,25°°°	15,55

Tableau

Type de sol	Horizon	Teneur en fractions			
		2—0 2 mm		0 2—0,02 mm	
		x	d	x	d
Chernozems modérément lévigués	A_a	0,30 / 2,39	+2,09***	35,37 / 51,45	+16,08***
	A_n	0,33 / 3,38	+3,05***	32,18 / 47,70	+15,52***
Chernozems fortement et très fortement lévigués	A_a	0,64 / 1,75	+1,11*	30,78 / 47,97	17,19***
	A_n	0,61 / 2,62	+2,01***	28,62 / 43,22	14,60***
Sols sylvestres bruns-roux	A_a	3,20 / 4,58	+1,38	34,89 / 48,11	+13,22***
	A_n	3,40 / 4,71	+1,31	30,52 / 44,46	+13,94***
Sols sylvestres bruns faiblement et modérément podzolisés et pseudogleyiques	A_a	4,18 / 5,36	+1,18	31,03 / 43,80	+12,77***
	A_n	3,48 / 4,46	+0,98	28,23 / 38,94	+10,71*
Sols sylvestres bruns fortement podzolisés pseudogleyiques	A_a	3,30 / 6,10	+2,80*	42,08 / 47,35	+5,27*
	A_n	4,35 / 7,95	+3,60***	36,73 / 40,77	+4,04

par des particules élémentaires plus petites qui, selon Nikolski (1956, 1961) participent à la formation des microagrégats en proportions variables. La teneur élevée en fractions grossières conditionnent l'ameublissement du sol et de bonnes relations avec l'eau et l'air, déterminant une perméabilité satisfaisante. Ces relations avec l'eau et l'air sont favorisées en même temps par l'existence d'une teneur réduite en microagrégats moyens.

Dans la littérature il y a des indications contradictoires en ce qui concerne les dimensions des particules élémentaires capables de participer à la formation des microagrégats. Ainsi, Dimo (1957) et Karnaoukhov (1957) considèrent que la microstructure se forme non seulement à l'aide de particules argileuses de 1μ, mais aussi avec la participation de la fraction de 5—1μ. Selon Kotcherina (1954) le rôle principal dans la constitution des microagrégats primaires revient à la fraction de 1μ. Les résultats obtenus nous

1 (suite)

microstructurales et granulométriques (%)								K_x
0,02—0,01 mm		0,01—0,002 mm		0,002—0,001 mm		≤0,001 mm		
x	d	x	d	x	d	x	d	
13,93	+3,91***	12,69	+7,36***	3,91	+0,12	33,80	—29,56°°°	12,54
17,84		20,05		4,03		4,24		
13,88	+2,55**	12,55	+8,83***	4,42	+0,50	36,64	—30,45°°°	16,89
16,43		21,38		4,92		6,19		
16,49	+1,57	13,78	+9,06	6,64	—1,92	31,67	—27,01°°°	14,71
18,06		22,84		4,72		4,66		
14,90	+1,75	13,34	+10,86***	6,26	—0,48	36,27	—28,74°°°	20,76
16,65		24,20		5,78		7,53		
16,12	+2,30*	13,93	+7,87***	4,96	—1,43	26,90	—23,40°°°	13,01
18,48		21,80		3,53		3,50		
14,46	+1,93	12,84	+9,66***	4,71	+0,31	34,07	—27,15°°°	20,31
16,39		22,50		5,02		6,92		
15,61	+2,61*	15,57	+8,13***	4,50	—0,42	29,11	—24,27°°°	16,62
18,22		23,70		4,08		4,84		
13,63	+2,25*	14,65	+10,20***	4,88	+1,49	35,13	—25,63°°°	27,32
15,88		25,85		6,37		9,50		
16,13	+1,50	15,68	+6,14***	3,68	—0,44	19.13	—15,25°°°	20,28
17,63		21,82		3,22		3,88		
14,49	+2,06	16,11	+7,23***	3,74	+1,64	24,58	—18,57°°°	24,44
16,55		23,34		5,38		6,01		

indiquent qu'entre les deux séries d'analyses il ya des différences très significatives pour les fractions argileuses de 1μ; on peut affirmer qu'elle ont un grand rôle dans la formation des microagrégats.

La valeur du facteur de dispersion varie entre 7,03 et 8,52 pour les chernozems et 10,32 pour les chernozems châtains de steppe. Ces valeurs nous indiquent une dispersion peu avancée et des conditions favorables pour la formation des microagrégats chez les chernozems. Le fait semble être dû à la teneur un peu plus élevée en argile qui, selon Puri et Rai (1944), a un rôle dominant dans l'agrégation des sols. Les différences entre les valeurs du facteur de dispersion sont significatives. Pour la partie inférieure de l'horizon A la dispersion est un peu plus avancée; de même les conditions pour la formation de microagrégats sont moins favorables. Bakhtine et collab. (1933) Iorlova (1959) et Baltiane et al. (1954) ont obtenu des données similaires.

Pour les sols de sylvosteppe limoneux et limoneux-argileux formés sur loess on constate également qu'à l'analyse microstructurale ont été obtenues des valeurs plus élevées qu'à l'analyse granulométrique pour toutes les fractions plus grandes que 2μ. La répartition des fractions microstructurales a, ici, un tout autre caractère. La teneur en fractions grossières — plus réduite que dans les sols de steppe — varie entre 59 et 50% et diminue lentement vers les chernozems très fortement lévigués. Les différences entre les deux séries d'analyses sont très significatives. Au contraire la teneur en fractions microstructurales moyennes est plus grande que chez les chernozems (4—41%); la plus grande valeur est caractéristique pour les chernozems très fortement lévigués. Les différences entre les données obtenues sont très significatives. Selon Rogovskaia (1961) les microagrégats moyens provoquent la détermination de la structure; les propriétés physiques deviennent ainsi moins favorables. Cette situation est favorisée par l'augmentation de la teneur en fractions fines qui varie entre 6% et 9,4% pour les sols très fortement lévigués. Les différences entre les deux séries d'analyses sont très significatives. La dispersion avancée et la hydrostabilité réduite sont illustrées encore par la valeur élevée du facteur de dispersion, qui varie entre 11,97 (chernozems faiblement lévigués) et 14,71 (chernozems très fortement lévigués); entre les valeurs citées il y a des différences significatives. Dans la partie inférieure de l'horizon A les conditions sont moins favorables, le facteur de dispersion ayant les valeurs 16—20.

Chez les sols sylvestres formés sur matériaux sédimentaires la distribution des fractions est la plus caractéristique. La moindre teneur en fractions microstructurales grossières a été constatée chez les sols sylvestres bruns podzolisés (49%); ici on constate aussi la plus grande teneur en fractions moyennes (42%) et la teneur la plus élevée en fractions fines (9%). La teneur réduite en fractions grossières et la presence de grandes quantités de fractions moyennes et fines souligne une fois de plus les propriétés hydrophysiques défavorables de ces sols. Les différences entre les résultats obtenus sont en général significatives. La valeur du facteur de dispersion croît jusqu'à 16, 62 pour les sols sylvestres bruns podzolisés et atteint la valeur 20, 28 pour les sols sylvestres bruns podzoliques. Ces valeurs indiquent uns stabilité très réduite, une dispersion avancée et une faible capacité potentielle pour la formation des microagrégats. La stabilité des microagrégats est encore plus faible et la dispersion encore plus élevée dans la partie inférieure de l'horizon A où le facteur de dispersion a les valeurs 24—27.

Les résultats présentés montrent que la hydrostabilité varie non seulement par rapport à leurs dimensions mais aussi par rapport au type de sol. La distribution quantitative de la teneur en fractions microstructurales est la résultante de l'influence exercée par de nombreux facteurs physiques, chimiques et minéralogiques. Néanmoins les résultats obtenus nous permettent d'entrevoir la nature des relations qui existent entre les données des analyses microstructurales et granulométriques. Les tentatives de corréler ces résultats ont été fructueuses pour la plupart des fractions étudiées (tabl. 2).

Tableau 2

La valeur du coefficient de corrélation r, entre les fractions microstructurales et granulométriques

Nr.	Dimension des fractions (mm)		Type de sol	r	Équation de la droite de régression
1	2—0,02		Tous les types de sols	+0,811	$Y = 0{,}902\,x + 9{,}38$
2			Idem, sans les sols sylvestres podzoliques	+0,872	$Y = 0{,}963\,x + 13{,}58$
3	0,2—0,02		Tous les types de sols	+0,807	$Y = 0{,}822\,x + 3{,}90$
4	0,002		Tous les types de sols	+0,798	$Y = 1{,}65\,x + 19{,}39$
5	0,001		Tous les types de sols	+0,705	$Y = 2{,}61\,x + 16{,}95$
6	0,2—0,02	0,001	Chernozems, chernozems p. et m. lévigués	—0,791	$Y = 0{,}612\,x + 621$
7			Tous les types de sols	—0,479	—
8	0,02—0,01		Chernozems, chernozems peu lévigués	+0,401	—
9			Chernozems, chernozems lévigués	+0,737	$Y = 1{,}13x + 7{,}64$
10	0,01—0,002		Tous les types de sols	+0,473	—
11	0,002—0,001		Tous les types de sols	+0,580	$Y = 2{,}63x + 18$
12			Chernozems	+0,457	—
13			Chernozems lévigués	+0,554	—
14			Chernozems lévigués	+0,554	—
			Sols sylvestres podzoliques	+0,557	—
15	0,02—0,002	0,02—0,01	Tous les types de sols	—0,333	—
16		0,01—0,002	Tous les types de sols	—0,550	$Y = 0{,}18\,x + 22{,}08$
17		0,002—0,001	Chernozems, chernozems m.et t. lévigués Sols sylvestres podzoliques	—0,211	—

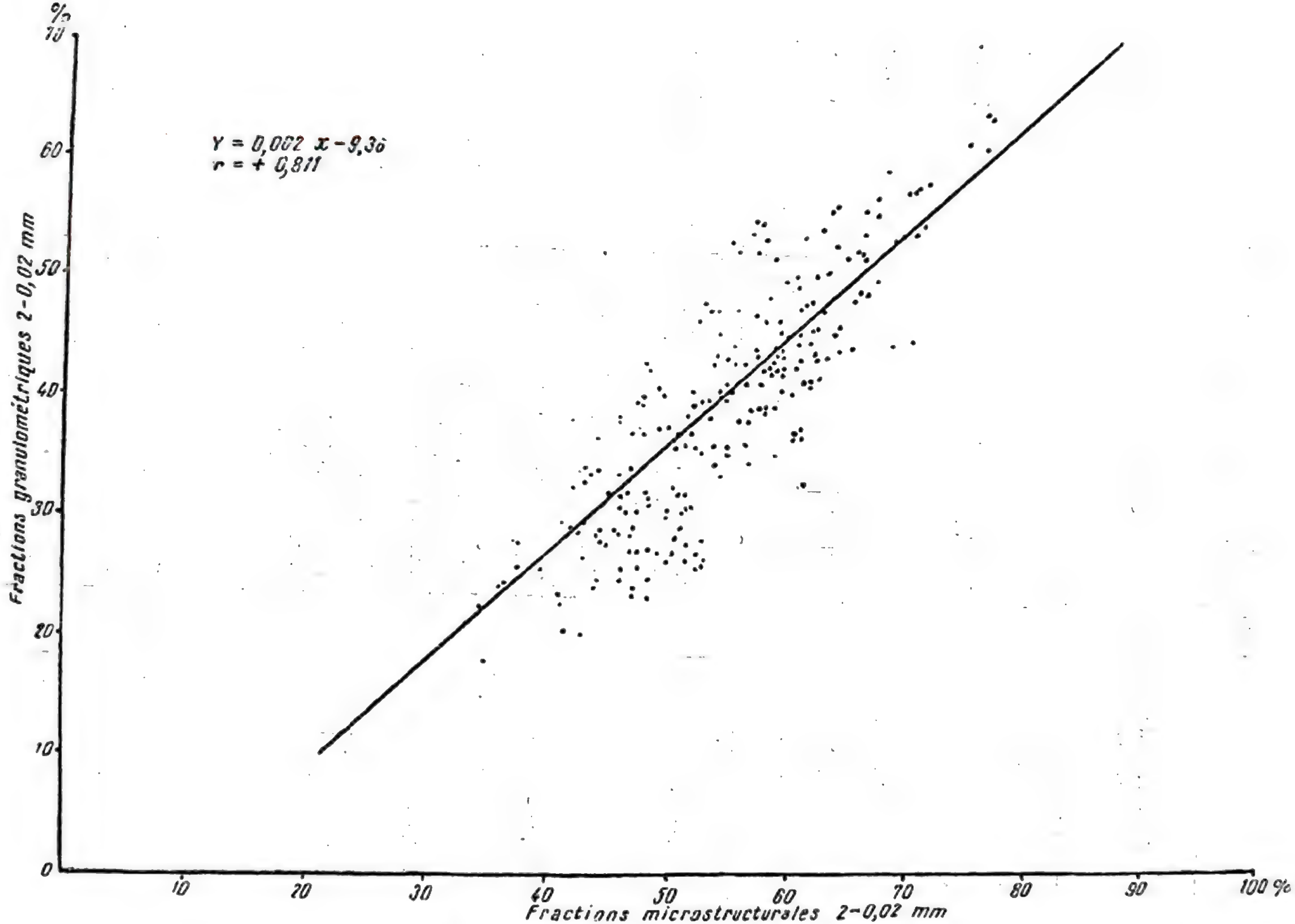

Fig. 1. La corrélation entre les fractions < 1 μ.

Ainsi, pour tous les sol des corrélations linéaires ont été établies entre les fractions de 1 μ (fig. 1), 2 μ (fig. 2) et entre les fractions grossières (fig. 3). La valeur des coefficients de corrélation (de +0,811 à +0,705) montre que les fractions microstructurales et granulométriques ayant la dimension mentionnée sont bien corrélées, c'est-à-dire qu'à la formation des microagré-

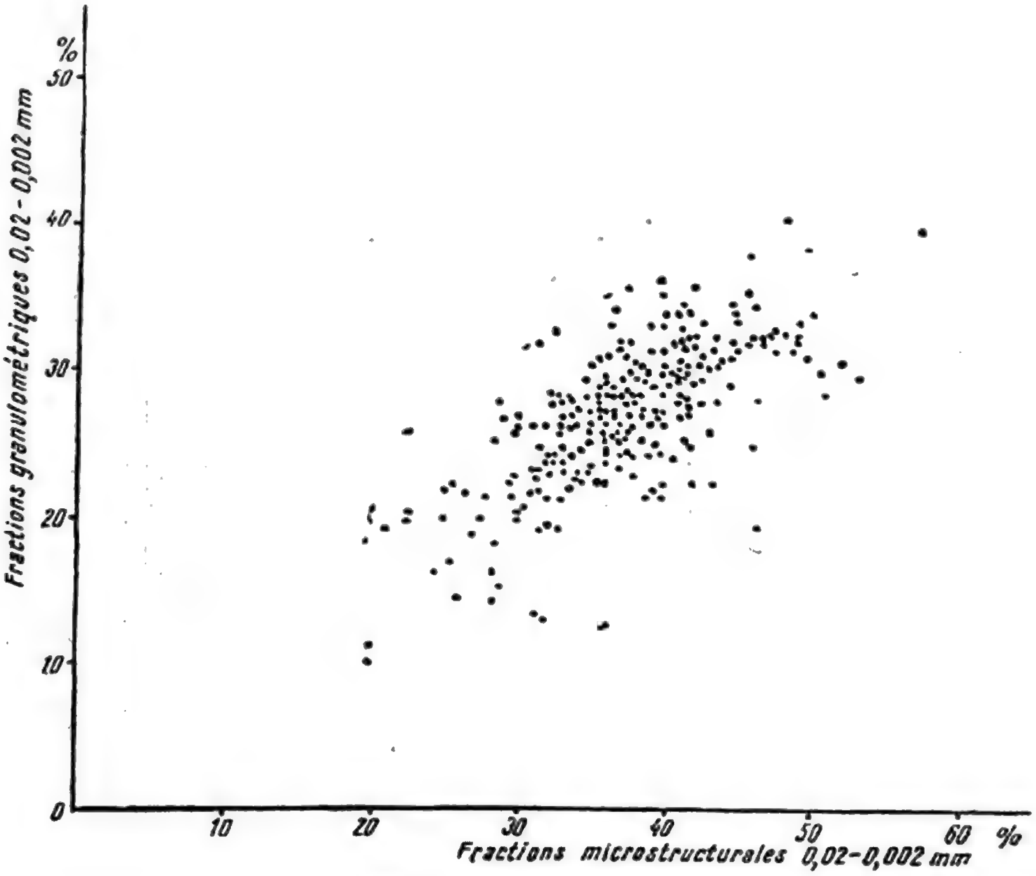

Fig. 2. La corrélation entre les fractions < 2μ.

gats un rôle important revient aux particules élémentaires ayant la même dimension. Font exception seulement les fractions moyennes (fig. 4) pour lesquelles une telle corrélation n'existe pas.

Des corrélations pour quelques-uns des sols étudiés ont été établies entre les particules élémentaires de 1μ et les fractions microstructurales de 0,2—0,02 mm (fig. 5) et de 0,01—0,002 mm (fig. 6). Les coefficients de corrélation montrent l'existence d'une liaison étroite ($r = -0,791$) seulement pour les chernozems et les chernozems peu et modérément lévigués dans le premier cas, et pour les chernozems et les chernozems lévigués — dans le deuxième cas ($r = -0,737$). La tentative d'étendre ce type de corrélation aux autres sols a provoqué la diminution du coefficient de corrélation à—0,401 ; les particules de 1 μ participent différentiellement à la formation des microagrégats.

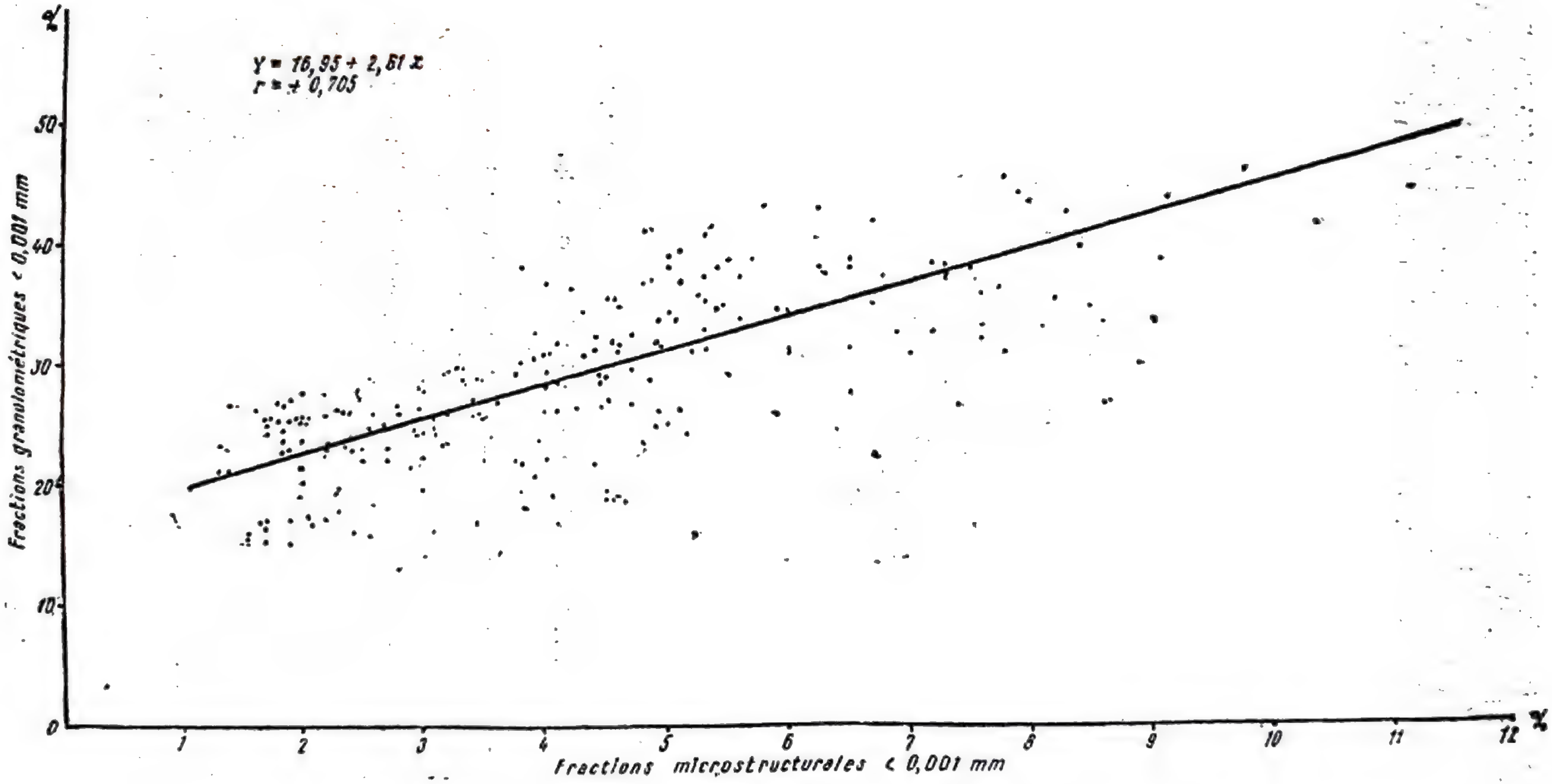

Fig. 3. La corrélation entre les fractions de 2—0,02 mm.

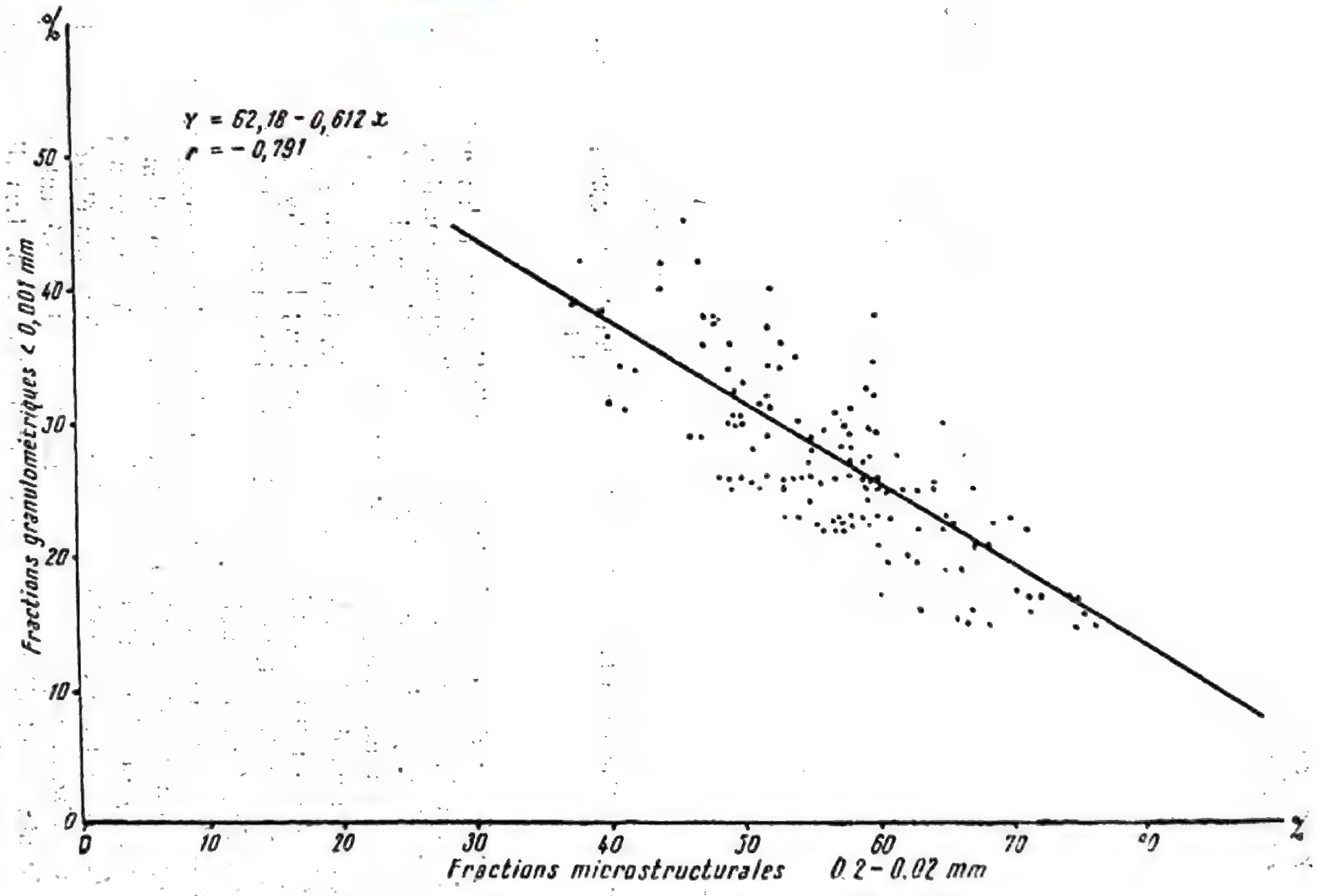

Fig. 4. La corrélation entre les fractions de 0,02—0,002 mm.

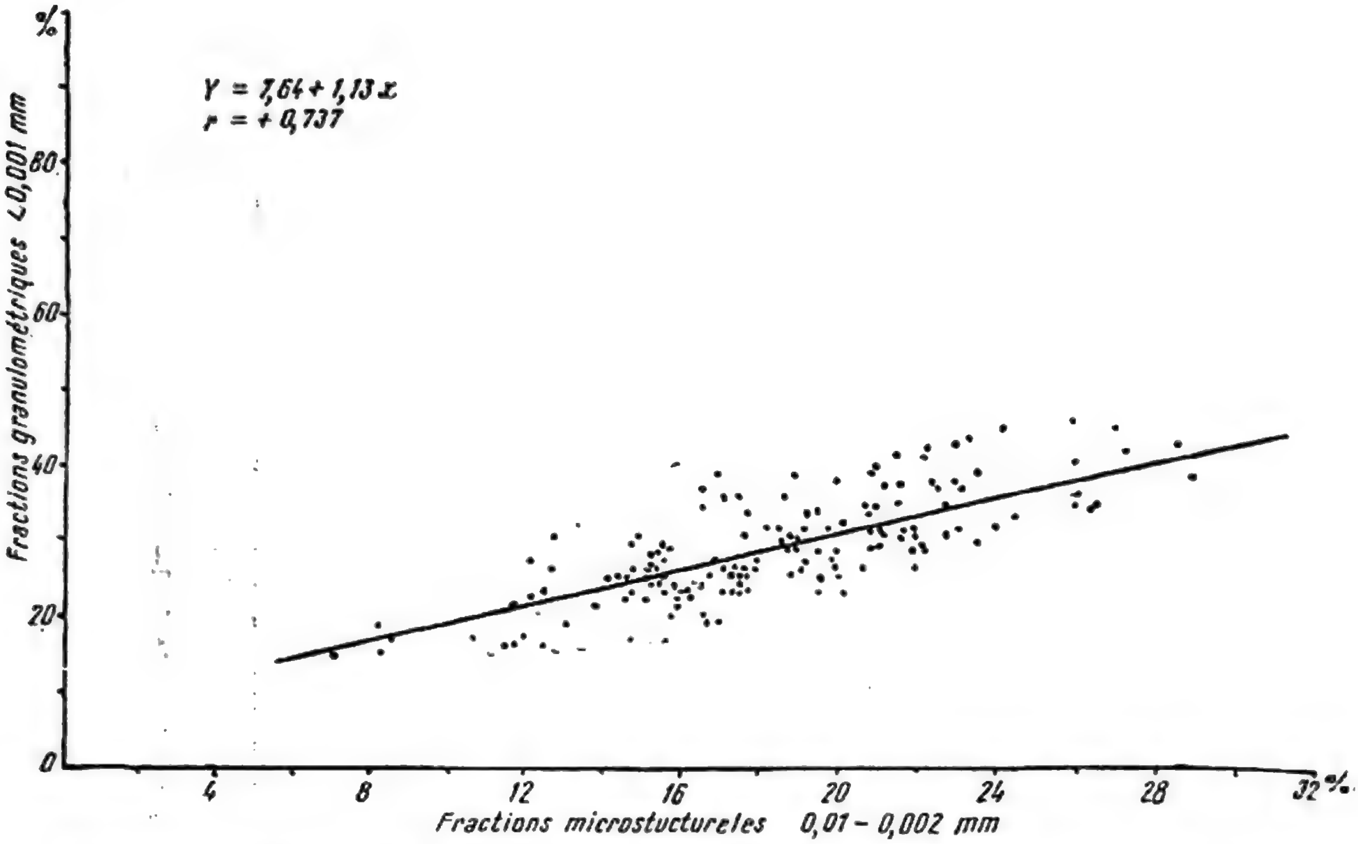

Fig. 5. La corrélation entre les fractions microstructurales de 0,2—0,02 mm et les fractions granulométriques $< 1\ \mu$.

Les valeurs des coefficients de corrélation pour les autres catégories de fractions microstructurales et granulométriques montrent l'absence de toute corrélation. Quoique entre les diverses fractions aient été établies quelques corrélations, elles ne sont pas significativement différentes, la séparation des types de sols étudiés n'étant pas possible. On remarque seulement les valeurs obtenues pour les microagrégats de 1 μ ; leur hydrostabilité est caractéristique pour tous les sols et doit être prise en considération à l'établissement du degré de dispersion.

Le facteur de dispersion présente des valeurs caractéristiques pour chaque type de sol (tabl. 3). Elles sont au minimum chez les chernozems châtains (7,03) et chocolat (8,52) croissent peu-à peu vers les chernozems lévigués (10,97—14,71) et atteignent les valeurs les plus élevées pour les sols sylvestres podzolisés (16,62—20,28). La hydrostabilité est meilleure pour les sols de steppe et diminue chez les sols sylvestres. Les différences entre les valeurs du facteur de dispersion sont significatives et peuvent caractériser le type générique de sol.

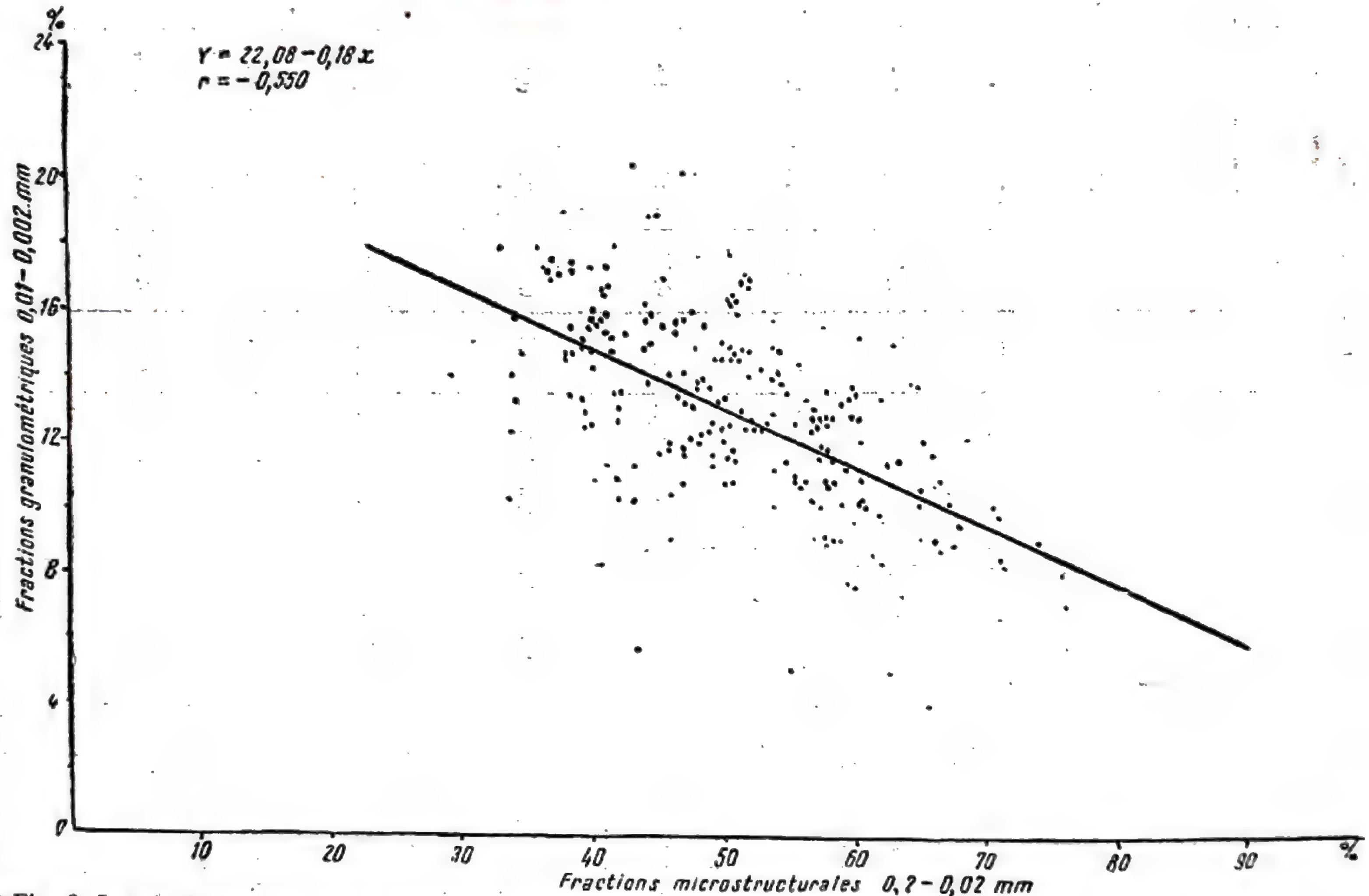

Fig. 6. La corrélation entre les fractions microstructurales de 0,01—0,002 mm et les fractions granulométriques < 1 μ.

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Tableau 3

La signification des différences entre les valeurs du facteur de dispersion

Type de sol	Facteur de dispersion K	Facteur de dispersion K_2	d	s_d	t_{28}	$P\%$	Signi-fica-tion
Chernozem châtain K_1	$7{,}03 \pm 0{,}30$	$8{,}52 \pm 0{,}38$	1,49	0,47	3,17	0,4	**
Chernozem chocolat K_2							
Chernozem chocolat K_1	$8{,}52 \pm 0{,}38$	$10{,}97 \pm 0{,}47$	2,45	0,60	4,08	<0,1	***
„ peu lévigué K_2							
Chernozem peu lév. K_1	$10{,}97 \pm 0{,}47$	$12{,}54 \pm 0{,}37$	1,57	0,60	2,61	1,4	*
„ mod. „ . . . . K_2							
Chernozem mod. lévig K_1	$12{,}54 \pm 0{,}37$	$14{,}71 \pm 0{,}60$	2,17	0,70	3,10	0,4	**
„ très. lev. . . K_2							
Sol sylvestre br. roux . . . . K_1	$13{,}01 \pm 0{,}36$	$14{,}71 \pm 0{,}60$	1,70	0,70	2,43	2,1	*
Chernozem très lév. K_2							
Chernozem très lév. K_1	$14{,}71 \pm 0{,}60$	$16{,}62 \pm 0{,}30$	1,91	0,67	2,10	4,4	*
Sol sylvestre brun podzolisé. . . . . K_2							
Sol sylvestre brun podzolisé. . . . . K_1	$16{,}62 \pm 0{,}30$	$20{,}28 \pm 0{,}76$	3,66	0,97	3,77	<0,1	***
Sol sylvestre brun podzolique . . . . . . K_2							
Chernozem châtain K_1	$7{,}30 \pm 0{,}30$	$10{,}32 \pm 0{,}12$	3,29	0,31	10,61	<0,1	***
Sol châtain de steppe K_2							
Chernozem chocolat K_1	$8{,}52 \pm 0{,}38$	$10{,}32 \pm 0{,}12$	1,80	0,40	4,50	<0,1	***
Sol châtain de steppe K_2							
Chernozem mod. levig. K_1	$12{,}54 \pm 0{,}37$	$13{,}01 \pm 0{,}36$	0,47	0,50	0,94	37,4	
Sol sylvestre brun roux K_2							

* Différences significatives (P entre 6% et 1%).
** Différences dist. signif. (P „ 1% „ 0,1%).
*** Différences très signif. (P sous 0,1%).

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RÉSUMÉ

On caractérise la microstructure des sols de steppe, de sylvosteppe et sylvestres conformément aux données des analyses microstructurales et granulométriques. La hydrostabilité des fractions microstructurales varie dans les sols étudiés par rapport à leur dimension. La teneur en fraction grossières est maximum dans les sols de steppe et minimum dans les sols sylvestres; la teneur en fractions moyennes est minimum dans les sols de steppe et maximum dans les sols sylvestres et celle en fractions microstructurales fines est minimum chez les sols de steppe et maximum dans les sols de sylvosteppe. Les différences sont en général significatives. Le facteur de dispersion présente des valeurs significatives pour tous les types de sol. Elles sont minima dans les sols de steppe et augmentent peu à peu vers les sols sylvestres. La capacité de former la microstructure est plus forte chez les sols de steppe que chez les sols sylvestres.

SUMMARY

The microstructure of steppe soils, of forest steppe- and forest soils, are characterized according to microaggregate and elementary particle size distribution analyses. The hydrostability of the microaggregate separates varies on the studied soils according to the size of the fractions. The content in coarse separates is maximum in the steppe soils and minimum in the forest soils; the content in medium sized separates is minimum in steppe soils and maximum in forest soils; the content in fine microaggregate separates is minimum in the steppe soils and maximum in the steppe forest soils. The differences are generally significant.

The dispersion ratio presents significant values for all soil types. They are minimum for the steppe soils and increase gradually towards the forest soils. The capacity of forming microstructures is stronger in steppe soils than in forest soils.

ZUSAMMENFASSUNG

Es wird die Mikrostruktur der Steppen-, Waldsteppen- und Waldböden nach den Angaben der Mikrostruktur- und Kornzusammensetzungs-Analysen charakterisiert. Die Wasserbeständigkeit der Mikrostrukturteilchen schwankt bei den untersuchten Böden im Verhältnis zu ihrer Grösse. Der Gehalt an groben Fraktionen ist bei den Steppenböden der höchste und bei den Waldböden der niedrigste; der Gehalt an Fraktionen mittlerer Korngrösse ist bei den Steppenböden der niedrigste und bei den Waldböden der höchste; endlich ist der Gehalt an feinsten Mikrostruktur-Fraktionen bei den Steppenböden der niedrigste und bei den Waldsteppenböden der höchste. Die Unterschiede sind im allgemeinen bezeichnend. Der Dispersionsfaktor zeigt bezeichnende Werte für alle Bodentypen. Diese sind minimal bei den Steppenböden und steigen allmählich zu den Waldböden an. Die Steppenböden zeigen eine grössere Fähigkeit zur Mikrostrukturbildung als die Waldböden.

DISCUSSION

L. L. DE LEENHEER (Belgique). Avez-vous étudié s'il y avait un rapport critique entre la teneur en matière organique et la teneur en argile pour une variation brusque du facteur de dispersion.

O. I. TEODORU. Je n'ai pas fait de déterminations de l'humus, pas plus que d'autres détermination qualitatives, ceci étant une première étape de l'étude. On a fait des déterminations quantitatives pour préciser la méthode de travail capable de fournir des résultats reproductibles pour toutes les catégories de micro-agrégats.

Les données de la littérature montrent que pour les sols de Roumanie il existe une bonne corrélation entre l'humus et l'argile. J'estime qu'il doit y avoir une telle corrélation aussi entre la teneur en humus et l'argile par catégories de micro-agrégats, ceux-là constituant les principaux facteurs qui contribuent à la formation des micro-agrégats et qui provoquent des variations dans les valeurs du facteur de dispersion. Nous nous proposons de poursuivre les recherches en ce sens, sous l'aspect minéraloqique et chimique.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 32

SEASONAL DENSITY CHANGES IN THE ALLUVIAL SOILS OF NORTHERN IRAQ

STUART A. HARRIS[1]

INTRODUCTION

It is well known that certain clay minerals expand on wetting. Since these are present in most soil materials, it is customary to expect that all soils will also expend on wetting. The measurements of Aitcheson and Holmes (1953) and Holmes (1952) support this conclusion, and most theories of gilgai formation assume that this is universally true (e.g. Edelman and Brinkman, 1961).

The Proctor test used in soil mechanics is based on the fact that compacting forces are much more effective on moist soil than dry soils. Thus if a parent material of a soil is under the influence of compacting forces and lacks expanding lattice clays, the question arises as to whether it should expand or contract, i.e. become more dense or less dense on being wetted.

The following paper describes the results of density determinations at different seasons on the alluvial soils of Iraq which are an ideal test case (Harris, 1958).

METHOD USED

Thin steel cylinders of about 8 cm diameter were jacked slowly into the carefully smoothed vertical face of the pit to a depth of about 7 cm. The cylinders were then dug out and the excess soil pared off the end of the tube. Cores showing distortion, or passing through visible cracks, mouseholes or roots were discarded. The length of the core was measured by difference and the soil was immediately dug out of the cylinder and sealed in a polythene bag. Wet weights and oven dry weights could then be obtained in the laboratory. Tests showed that there was negligible loss in moisture over several weeks after sealing in the polythene bag.

From the results, dry density (defined as dry weight divided by wet volume) and wet density (defined as wet weight divided by wet volume) could be calculated. For use in soil structure studies, the moisture content was plotted against dry density.

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RELIABILITY OF THE CORE METHOD

Twelve days after the previous rains, a shallow trench was dug in a uniform silt horizon of a soil near Kirkuk, Northern Iraq. Nine replicates were made, one beside the other, in a trench at the same depth in a period of about two hours. The small variation in the results (table 1) appears to indicate that the core method is reasonably accurate, and that the degree of compaction and dry density were fairly constant over a distance of 5 meters. Moisture content varied more than dry density but was still fairly constant.

Table 1

Variation in the results of nine replicate density determination for a uniform horizon in a Dingawa soil near Kirkuk

Sample	Moisture Content %	Dry density (gm/cm^3)	Wet density (gm/cm^3)
Mean	16.9	1.42	1.66
Range	+1.7 —1.3	+0.02 —0.02	+0.04 —0.03
Standard deviation	0.90	0.014	—

FACTORS FOUND TO AFFECT DENSITY RESULTS

The factors examined in the present study are moisture content, texture, depth, aggregate stability, salinity and soil type. No data are available on the Iraq soils regarding grading, method of packing, or grain shape. Alkaline carbonates which are commonly present to about the 25—36 per cent level, do not appear to move much except under extremely wet conditions in marshes. There, in the dry state, a certain amount of cementation may occur in the upper horizons. The percentage of other water soluble salts is always too low for solution to be important.

1. *Moisture content*

There is evidence that greater variability in density and moisture content occur just after rains (see table 2). To overcome this, all subsequent tests were carried out at least one week after the last rains.

Table 2

Relationship between reproducibility of density data and incidence of last rains, (Pit 11, near Baquba)

Date tested	Time after last rains days	Range of dry density (gm/cm^3)	Range of moisture Content	No. of samples
20.3.57	7	0.10	6.0	10
14.5.57	1	0.14	10.9	7
Kirkuk replicates Table 1	14	0.04	3.0	9

Figure 1 shows the result of plotting all the data in the form of a moisture content-dry density graph. The lowest limits for density in the wet season are appreciabily above those for the summer season, while the

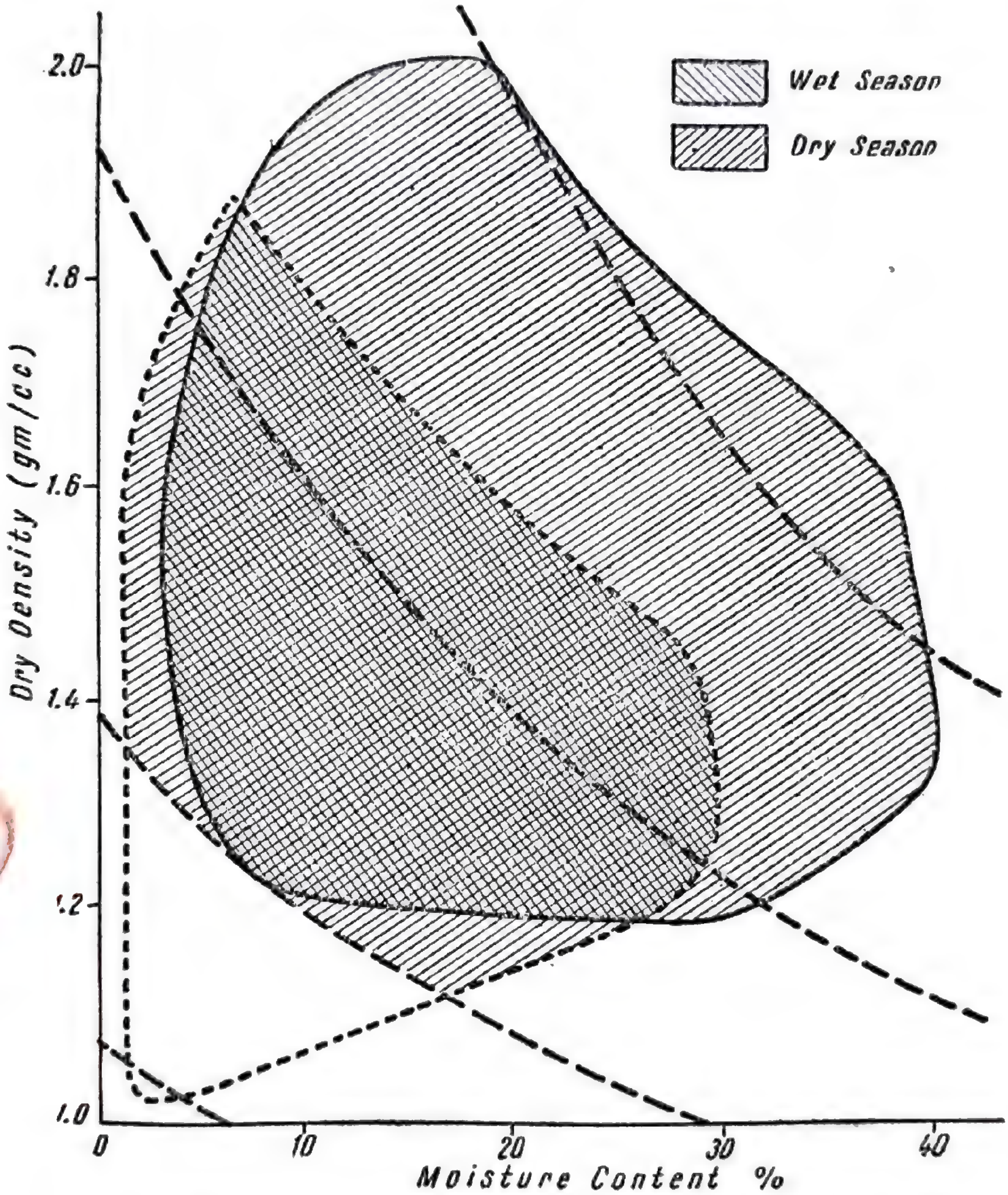

Fig. 1. Density variation with moisture content for soils from Central Iraq.

upper limit of densities in summer is considerably below that for winter. There is therefore evidence for an increase in density and in degree of compaction with increase in moisture content.

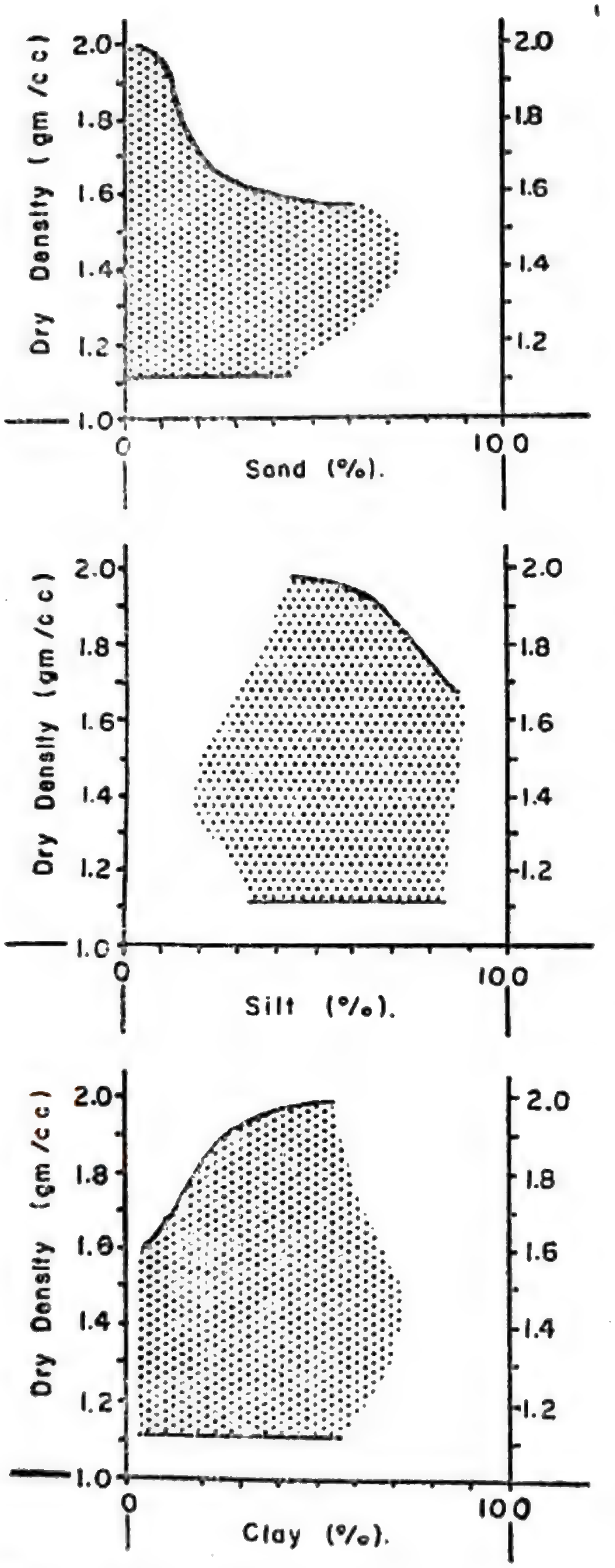

Fig. 2. Relationship between texture and dry density in the lower Diyala area.

Further evidence was obtained from studies in fresh pits at the same site in both the wet and dry seasons. The area in which this effect was studied lies just to the north of Baghdad. The climate can be divided into a dry, hot summer and a moderately wet, fairly cold winter. There is little "spring" or „autumn" as an intermediate season unless the rains either end early before the summer heat, or begin very late. The climatic norms for Baghdad will be found in Govt.of Iraq (1954).

In the field season 1956—1957, a marked "autumn" occurred, the first rains not falling until halfway through January. The opportunity occurred for sampling at the end of the long dry season, which should correspond to an unusually dry state.

Thereafter rain fell periodically until the end of June. The difference between the results obtained in 24 pits tested in both wet an dry seasons are given in the form of a correlation table in table 3. The classes for difference in dry density chosen are equal to twice the range of variation in the Kirkuk replicates.

2. *Texture*

The dry density was plotted against sand, silt and clay content in turn (see fig.2). The upper limit of density range in all cases is markedly related to texture. There appears to be a rapid fall off where more than 10 per cent sand,

Table 3

Correlation table for differences in moisture content and dry density for the horizons tested in both dry and wet season

Difference in dry density (gm/cm^3) (wet-dry season value)	Difference in moisture content (%) (west-dry season value)			Total
	0—10	10—20	20—30	
—0.08	1	1	0	2
—0.08 to 0.00	2	1	0	3
0.00 to 0.08	1	4	0	5
0.08	6	6	2	14
Total	10	12	2	24

more than 70 per cent silt and less than 30 per cent clay are present. Remembering that we are dealing with a limited amount of data, it would seem that about 30 per cent clay is required to give really high densities in the wet season. Dilution below this amount with either silt or sand reduces the upper density limit to between 1.5 and 1.6 gm/cm^3 .The lower limit of density range appears to be about 1.14 gm/cm^3 in all cases.

Thus texture appears to be important in controlling possible ranges of density and moisture content. At the moment, insufficient data are available to be able to relate actual limits to the texture triangle. In all comparisons of data where texture could be important, enough data must be averaged to eliminate the effect of textural variations.

3. *Depth and aggregate stability*

Averages of large numbers of determinations revealed definite evidence for compaction variations with depth (see table 4). This is to be expected

Table 4

Depth and seasonal averages of the density and moisture content for well and badly structured horizons

Season	Depth cm	Aggregate stability of dry horizons							
		High				Low			
		No. averaged	Dd (gm/cm^3)	m (%)	Average depth (cm)	No. Averaged	Dd (gm/cm^3)	m (%)	Average depth (cm)
Wet	0—50	26	1.58	17.7	25	20	1.41	17.4	25
	50—100	25	1.58	18.8	77	19	1.39	15.8	69
	100—150	11	1.67	15.2	131	28	1.52	15.9	126
Dry	0—50	54	1.47	7.6	25	19	1.40	9.2	32
	50—100	19	1.47	11.8	73	12	1.40	10.8	73
	100—150	2	1.30	7.5	118	10	1.35	11.7	131

since the moisture content of the soil is controlled at least in part by the proximity of the horizon to the water table and to rain water. Thickness of overburden is probably only a minor factor in these soils, while clay movement is negligible.

The soil horizons the alluvial soils can also be divided into two broad groups on the basis of consistency in dry weather. Those with high aggregate stability in dry weather are called the "badly structured soils" (Harris, 1958), while the "well structured soils" have low dry aggregate stability.

The extreme case of "bad structure" is marked by gilgai, i.e. a characteristic microrelief found in soils in many parts of the world which are subject to marked seasonal fluctuations in moisture content. The Iraqi cases lack the puff or upraised portion of many Australian and E. African examples.

In table 4, the average density results for the dry season are again lower for the wet season. Closer examination shows that the average for horizons with high dry aggregate stability are more dense than those for low dry aggregate stability. This difference is much more marked in the wet season.

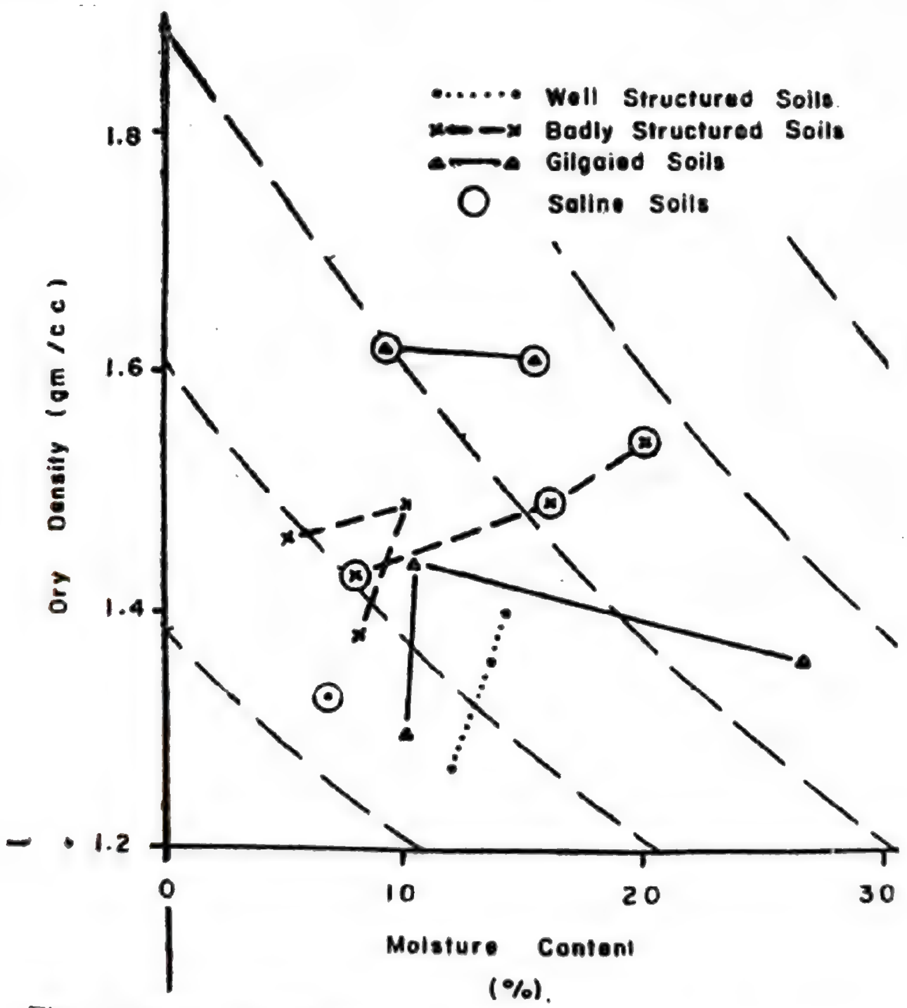

Fig. 3. Density distribution in the dry season for the various units mapped in the Lower Diyala area, Central Iraq.

Greater seasonal variation of both density and moisture content occurs in the deeper layers of horizons with high dry aggregate stability than low dry aggregate stability. This is presumably due to the deep vertical cracking which is widespread in the poorly structured soils in the dry season and may extend below 200 cm in depth in gilgai. This permits wetting from the bottom of the cracks upwards at the beginning of the wet season and must also facilitate drying in summer.

4. *Salinity and soil type*

Since the horizons of low and high dry aggregate stability may occur in the same profile, it is more realistic to consider the average densities of the three types of soil from complete profiles. The results for these are shown in table 5, while they are shown graphically in figures 3 and 4.

Table 5

Seasonal density distributions in the fine textured units mapped in the lower Diyala area, Central Iraq

Salinity	Profile type	Depth cm	Dry season			Wet season		
			Average moisture content (%)	Average dry density (gm/cm^3)	No. of samples averaged	Average moisture content (%)	Average dry density (gm/cm^3)	No. of samples averaged
Non saline or slightly saline (E.C. 8 mmhos/cm)	Well structured soils	0—50	14.3	1.40	4	15.8	1.50	6
		50—100	13.7	1.36	4	13.7	1.51	5
		100—150	12.0	1.27	3	10.8	1.48	7
	Poorly structured soils	0—50	5.1	1.46	21	18.2	1.58	14
		50—100	10.2	1.49	11	16.0	1.59	17
		100—150	8.2	1.38	3	16.5	1.73	12
	Gilgaied soils	0—50	10.1	1.30	17	25.1	1.61	2
		50—100	10.6	1.44	4	22.6	1.62	3
		100—150	26.6	1.36	1	17.3	1.71	3
Saline or moderately saline soils (E.C.8 mmhos/cm)	Well structured soils	0—50	6.8	1.33	5	15.3	1.48	12
		50—100	—	—	—	16.2	1.47	10
		100—150	—	—	—	13.1	1.43	12
	Poorly structured	0—50	8.0	1.43	10	17.6	1.50	6
		50—100	16.2	1.49	4	22.7	1.57	6
		100—150	20—2	1.54	1	21.3	1.62	4
	Gilgaied soils	0—50	9.5	1.62	9	—	—	—
		50—100	15.6	1.61	3	—	—	—
		100—150	—	—	—	—	—	—

In the wet season, the limited available data for gilgaied soils suggest a progressive increase in density and decrease in moisture content with little change in degree of compaction with depth. There is a gradation from the dense gilgai to the less dense, well structured soils associated with a change in den-

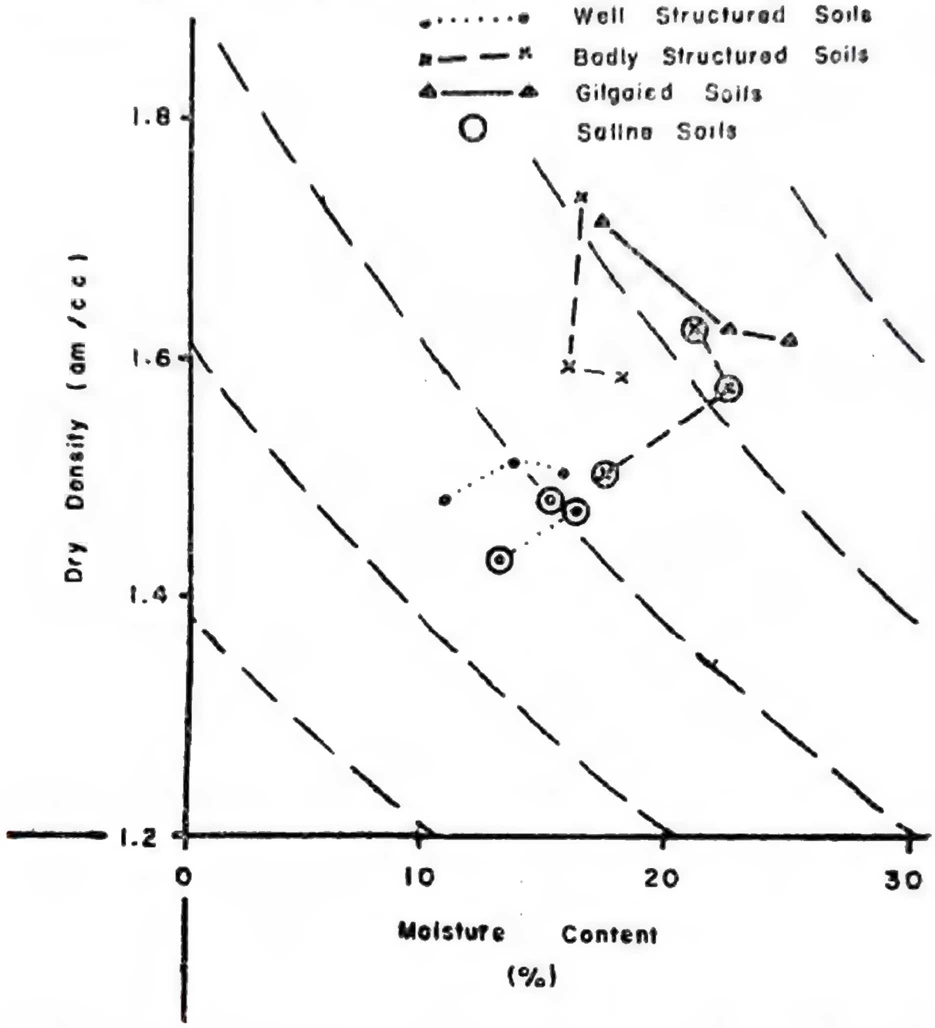

Fig. 4. Density distribution in the wet season for the various units mapped in the Lower Diyala area, Central Iraq.

sity distribution with depth. The horizons of bad structured soils are less compact and tend to be less dense the gilgaied soils. The well structured soils are decidedly less dense and compact than the other soils, and show a marked decrease in compaction, density and moisture content with depth.

The saline examples are less dense than the non-saline soils. In the non-saline bad structured soils, the horizons increase in density and degree of compaction below 100 cm, whereas in the corresponding saline soils, a decrease occurs. This could be due to lack of data.

In the dry season, all the soils tend to become less dense in the area, although the gilgaied profiles and bad structured soils tend to lie on the more compact side. The non saline well structured soils show a decrease in density,

moisture content and compaction with depth as before, while the saline counterparts are not so dense or compact. In the bad structured soils, the saline and non-saline groups start at similar densities. Whereas the non-saline profile shows first an increase and then a decrease in degree of compaction, the saline equivalent becomes progressively more compact and moist with depth. The saline gilgai soils are considerably more dense than the nonsaline gilgai soils.

DISCUSSION

It is clear that a marked increase in density and degree of compaction occur when the winter rains begin. To achieve this, the soil must contract in volume at this time. The vertical cracks of the gilgai can only be filled in by downwash of soil and by soil flowage. This agrees with the lack of appreciable surface expression of the channel-shelf topography at this time and the soupy nature of the soils in gilgai channels.

The micro-relief appears to be most marked in the dry season, and it must be during the drying process that the main movements involving expansion take place. The shelf dries first presumably expanding and rising as it does so. It continues to dry and rise as the drying and expansion process slowly spreads into the channel. Once the entire surface has dried, compensatory flowage of moist soil material would occur to release the tensions set up as the drying process continued. Figure 5 shows the postulated cycles diagrammatically. Obviously, if this theory is correct upraised puffs would be unlikely

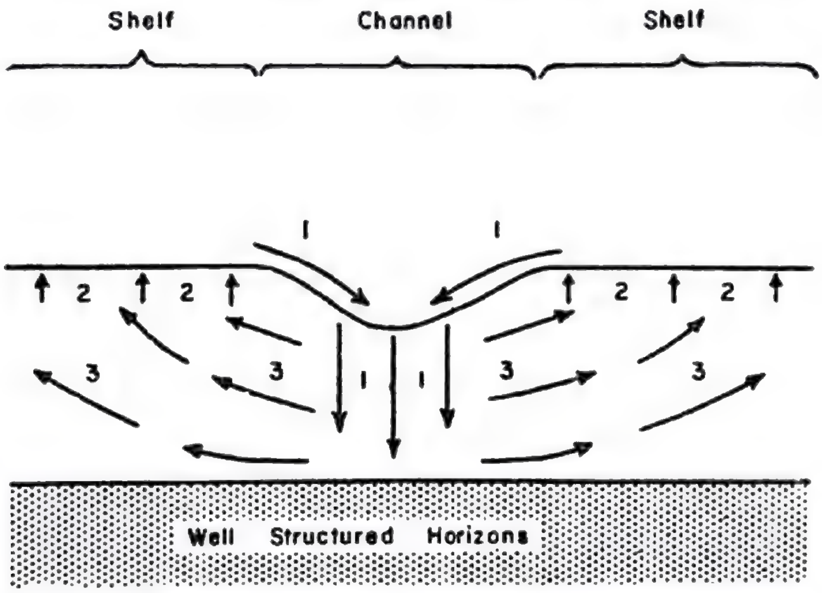

Fig. 5. Diagram to show the cyclical movements postulated in gilgai genesis and maintenance in Iraq : *1.*—sheet wash and soil early flowage ; *2.*—relatively greater expansion of the shelf during the eraly stages of drying ; *3.*—compensatory soil flowage during the later drying stages.

to occur in these gilgai, unlike those formed on swelling clay soils. Amplitude and wave length of shelf and channel would depend on the mechanical properties of the soil materials during the various processes.

The lack of dependence on expansion of lattice clays helps to explain why gilgai microrelief can be very marked in soils with 96 per cent silt. The higher the silt-clay ratio, presumably the smaller the influence of the expanding lattice clay minerals during moisture changes and the greater the influence of natural soil compaction phenomena.

CONCLUSIONS

1. Density determinations by the core method can be very accurate, standard deviations for dry (bulk) density being as low as 0.01 gm/cm^3 for 10 replicates of a single horizon.
2. Moisture content is the most important factor affecting the density and degree of compaction of the soil. Increase in moisture content causes an increase in degree of compaction.
3. Rain causes uneven wetting of the soil, probably due to penetration in vertical cracks. It takes about one to two weeks for the moisture to spread fairly evenly laterally through the soil.
4. Onset of the rainy season is followed by a fairly rapid increase in density and degree of compaction to suit the new conditions. In an extreme case, the density may change from 1.29 gm/cm^3 in the dry season to 1.97 gm/cm^3. It must be accompanied by soil contraction.
5. Texture of the soil controls the seasonal changes in moisture content and the density.
6. Depth of the sample is another important factor, chiefly because it controls the liability to wetting by rain or by the groundwater. The effect of overburden is small by comparison.
7. There is a good correlation between soil consistency and the density compaction and moisture content regimes.

   Moisture penetration is noticeably higher in soils with strong vertical cracking. Thus there is good correlation of density with mapping units.
8. In the wet season, the gilgai are far more dense than the wel structured soils but in the dry season these differences tend to disappear.
9. Saline gilgai are more compact than non-saline gilgai in the dry season, presumably due to the sodium clays.
10. The expansion forming the gilgai microrelief must occur during the drying phase in these soils.

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SUMMARY

The alluvial soils of Iraq lack appreciable quantities of expanding lattice clays and have a high silt content. In spite of this, they frequently exhibit gilgai microrelief.

Density determinations show that there is a marked increase in density and degree of compaction with the onest of the rainy season. This implies a contraction of the soil on wetting and an expansion on drying. Actual variables correlating with increased density and degree of compaction are increased moisture content, non sandy texture, shallow depth, good dry aggregate stability (poor soil consistency) and high salinity. These variations show up well in the mapping units.

It is concluded that the main swelling action in gilgai formation takes place as the sheld dries out. Compensatory soil flowing presumably occurs after the surface of the channel has dried out. The vertical cracks are infilled by sheet wash and by soil collapse at the beginning of the wet season.

RÉSUMÉ

Les sols alluviaux de l'Iraq manquent de quantités appréciables d'argile à réseau extensible et ils contiennent une grande proportion de limon. Malgré ceci, ils montrent souvent le microrelief „gilgai".

Des déterminations sur la densité démontrent une augmentation évidente quant à la densité et le degré de compacité dès que la saison pluvieuse commence. Ce fait implique une contraction du sol quand il devient mouillé et une expansion quand il devient sec. Les variables réelles qui sont corrélatives, avec la densité accrue et le degré de compacité, sont une plus grande quantité d'eau, une texture non-sablonneuse, une profondeur superficielle, une bonne stabilité pour les agrégats secs (faible consistance du sol) et une salinité élevée. Ces variations se reflettent très bien dans les unités cartographiques.

On conclut que le gonflement dans la formation des „gilgai" se produit quand le „shelf" se dessèche. Un écoulement compensatoire du sol se présente probablement après que la surface du „channel" s'est desséchée. Les fissures verticales sont remplies par la déposition de matériel entraîné par le ruisselement en nappe et par l'écoulement du sol au début de la saison pluvieuse.

ZUSAMMENFASSUNG

Den alluvialen Böden Iraks fehlt es an beträchtlichen Mengen von ausdehnbaren Gittertonen und sie weisen einen hohen Gehalt an Schluff auf. Trotzdem zeigen sie oft einen Gilgai-Mikrorelief.

Dichtebestimmungen zeigen dass mit Beginn der Regenjahreszeit sich eine beachtliche Steigerung in Dichte und Verdichtungsgrad einstellt. Dies begreift eine Zusammenziehung des Bodens bei Durchfeuchtung und eine Ausdehnung bei Austrocknung mit ein. Aktuelle Variablen, die mit gesteigerter Dichte und gesteigertem Verdichtungsgrad korrelieren sind ein höherer

Wassergehalt, eine nicht-sandige Textur, eine kleine Machtigheit, eine gute Beständigkeit der Trockenaggregate (schwache Bodenkonsistenz) und eine hohe Salzhaltigkeit. Diese Veränderungen drücken sich gut in den kartographischen Einheiten aus.

Es wird die Schlussfolgerung gezogen, dass die Hauptschwellungswirkung in der Gilgaibildung dann stattfindet, wenn der „shelf" austrocknet. Es kommt vermutlich ein Bodenfliessen vor, nachdem die Kanaloberfläche ausgetrocknet ist. Die senkrechten Risse werden durch Schichtflut und durch Bodeneinsturz gefüllt, bei Beginn der nassen Jahreszeit.

DISCUSSION

D. HILLEL (Israel). 1. It is commonly known that clayey soils swell when they absorb water and shrink when they dry out. Your data seem to show that the soils under study shrink upon wetting and swell upon drying. Can you postulate a mechanism to explain such surprising soil behavior?

2. You used the core-sampling technique to measure bulk density and showed that it gave consistent results. Our experience shows that it is difficult to obtain undisturbed cores when the soil is either too wet (when it is highly compactible) or too dry (when it is hard, easily shattered and highly resistant to cutting. Did you compare the bulk density measurements made by core-sampling to measurements by some other independent method?

S. A. HARRIS. 1. Builders often use this compaction technique in compacting sands. After spreading the loose sand on, say, a garage floor, they sprinkle water on to it, and the sand packs down to between two-thirds or three-quarters of its dry loose volume. In laboratory experiments, using the Iraqi alluvial soils, it can be shown that a more limited expansion or decrease in compaction takes place during the drying phase. After about two more wetting and drying cycles, the density becomes predictable and consistent for any part of the cycle. A hysteresis effect is found in which there is a slight lag in the modification of the density with change of moisture conditions. Similar results can be obtained with other soils which have a low proportion of swelling clays, and the Chief Engineer of Messrs. Wimpey & Sons, Ltd., England, told the author that he estimated that about one third of the soils of the world may have similar moisture-density regimes to these soils from Iraq. The soils, with gilgai mapped as solodized-solonetz intergrades in Western Rumania and shown to us on tour 2, looked as though they might be an example.

The mechanism is a problem. As a former soil surveyer, I am using this paper to bring the problem to the notice of those of you who are much better trained and equiped to tackle it. There are occasional vague references to latent interparticle forces in literature[1] but otherwise the possibility of such a process has been completely ignored. It seems strange that so little work has been carried out on seasonal changes of physical properties in the field. The results presented here would appear to indicate that these changes may be very great, while the writer has elsewhere[2] shown that the density conditions, not necessarily the soil consistency and structure, control the native vegetation in Iraq. More work is obviously needed, but in the opinion of the writer, density-moisture content studies may well prove the best test of physical soil condition in the field.

2. Yes, density under dry and very wet conditions is impossible to determine using the core method. This is why there are no absolutely dry soils or extremely wet soils included in the tests. The precautions taken included using a straight-edged board to check that the sides of the pit had not been pushed in, and also measuring inside and outside lengths of the projecting coring tubes.

The method was checked against that of taking soil lumps and coating them with parafin wax in the field. The results gave good agreement but the core method was easier for me, hence its adoption. In any case, if the method had been faulty, it would have been faulty for all the samples, i.e. the errors should have been consistently in one direction, or else should have cancelled one another out if enough samples were averaged. In the first case, the actual values would be wrong but the *difference* between the values would be correct.

[1] HARRIS, S. A., *The distribution of certain plant species in similar desert and steppe soils in Central and Northern Iraq*. Journ. Ecology, 48: 94—105, 1960.

[2] PARRY, R. H. G., Nature, 183: 538—539, 1959.

It is perhaps worth adding that the method of study ignored the spaces in cracks between the larger structured elements since these could not be adequately estimated. These spaces represent an additional increase in air spaces, i.e., still lower density, in the dry season.

Thus the differences are probably reliable and perhaps underestimated provided that enough samples are averaged.

A. CANARACHE (Rumanian People's Republic). You have presented data on sampling variation only for samples obtained from one and the same trench, and this sampling variation is rather small. Have you also taken into account the much greater sampling variation between trenches, or have you used an adequate sampling design?

S. A. HARRIS. The sampling variation given here is typical of what was obtained elsewhere in trenches in the alluvium. However alluvium is inevitably very variable from place to place. The main differences from site to site are texture, structure, moisture content and salinity. In choosing the sites of tests, we attempted to include strata covering the full range of textures and structure in about the proportions in which they were encountered in the grid boreholes, one hole per square kilometer, covering an area of about 10,000 square kilometers. We also tried to cover an adequate number of saline soils for comparison.

Thus the main deficiency is likely to be in numbers of samples averaged in tables 4 and 5. For this reason, the number of samples used is included so as to give the reader an idea of the reliability of the average. This weakness is fully realized and I have not attempted to hide it. The number of samples needed to overcome this problem was too great bo to a practical proposition. However the results are consistent and present a sufficiently different pattern to what had hitherto been assumed to appear to warrant presentation at this Congress.

DIAGRAMME TERNAIRE POUR REPRÉSENTER LA TEXTURE DU SOL DANS LA CLASSIFICATION INTERNATIONALE

MIRCEA POPOVATZ [1]

La nécessité d'une classification de la texture des sols à utilisation universelle est incontestable. Malheureusement, il existe une très grande diversité dans le mode de définir des classes de texture. Celle-ci tient à deux causes : 1) l'absence d'unité quant aux limites des dimensions des fractions sable et limon, même si on est tombé d'accord, en général, de considérer comme argile la fraction dont les particules ont moins de 0,002 mm, et 2) le taux des trois fractions d'une même classe diffère d'un système à l'autre, et dans presque chaque pays on emploie un ou plusieurs systèmes particuliers.

Parmi les classifications existantes, celle du Département d'Agriculture des États-Unis d'Amérique, fruit d'une vaste expérience, a trouvé le plus de faveur. Elle n'a pas été adoptée toutefois comme classification internationale. La principale raison en est la limite 0,05 mm entre sable et *silt*, ce qui rend impossible la comparaison directe avec des résultats d'analyses granulométriques effectuées selon le système d'Atterberg, à limite 0,02 mm, admis à l'échelle internationale. D'autre part, selon nous, l'intervalle fixé pour la fraction *silt* étant très large (0,05—0,002 mm) les classes à *silt* sont trop fournies, au détriment d'autres classes.

Prescott, Taylor et Marshall (1934) ont proposé un diagramme ternaire dans le système international, issu de la corrélation entre les résultats des analyses granulométriques des échantillons de sols effectuées dans le système américain et celui international. Les échantillons ont été choisis parmi ceux représentatifs pour chaque classe texturale. Cette corrélation ne peut plus être prise en considération, puisqu'en 1937 l'U.S.D.A. a adopté la limite 0,002 mm pour l'argile[2].

Sans passer en revue les nombreux travaux publiés, nous mentionnons que, plus récemment, Franzmeier, Whiteside et Erickson (1960) ont établi une corrélation entre les classes de texture et la capacité pour l'eau „aisément accessible". Les auteurs montrent la relation entre les valeurs de la capacité pour l'eau aisément accessible et les différents systèmes de

[1] Comité Géologique, Bucarest, RÉPUBLIQUE POPULAIRE ROUMAINE.

[2] Nous rappelons que jusqu'en 1937 la fraction silt était plus restreinte (0,05—0,005 mm).

représentation graphique des classes de texture, sans recommander aucun diagramme.

Dans ce qui suit nous nous proposons de définir des classes de texture comprises dans le système international, fondées sur les caractères spécifiques des granules, c'est-à-dire leurs dimensions mêmes. À cet effet nous avons choisi comme critérium l'ensemble des valeurs calculées à partir des données analytiques, et que nous appellerons indices de texture. Parmi les nombreuses façons existantes de définir de telles valeurs, la nôtre fournit des indices dont l'application est possible sur une très grande gamme de textures, des plus fines aux plus grossières (Popovatz, 1943). Il y a deux indices principaux, le diamètre moyen *Dm* et le degré d'homogénéité *H*. Un troisième indice, le degré de finesse, *F*, est obtenu comme produit des valeurs des deux premiers.

Pour déterminer les limites des classes de texture, c'est à des ouvrages publiés que nous avons emprunté les données analytiques concernant des échantillons à texture très variée, disséminés sur tout le globe. Nous avons choisi 106 sédiments meubles et 193 échantillons de profils de sols, dont une bonne part de Roumanie. Après un examen très attentif, au moyen de courbes de sommation, nous avons éliminé 19 échantillons dont l'allure de la courbe montrait qu'il était question de matériaux à la formation desquels avaient contribué deux agents différents. Les indices de texture de tels échantillons ne sont pas toujours concluants, tandis que leur classification texturale n'est ni aisée, ni précise.

Les indices de texture des échantillons que nous avons calculés ont été représentés en un système de coordonnées rectangulaires, en portant en abscisse log *Dm* et en ordonnée *H* (fig. 1). Sans faire encore aucun groupement des points obtenus, nous avons reporté la composition granulométrique des échantillons dans un triangle dont les sommets représentent les trois fractions principales du système international, 2—0,02, 0,02—0,002, < 0,002 mm (fig.2).

Pour le groupement des classes dans le triangle, on s'est tenu, autant que possible, aux limites du taux d'argile du système U.S.D.A. C'est ainsi qu'on a compté comme argiles les classes à plus de 40% d'argile (sauf l'argile sableuse, à 35%). Pour le limon, classe importante dans la texture des sols de Roumanie, on a maintenu les limites du système américain, 7 à 27% d'argile. Nous n'avons fixé, au comencement, aucune limite pour le sable et le silt.

Voici le procédé suivi pour arriver à fixer les limites de toutes les fractions. Dans le graphique de la figure 1 on a esquissé, en première approximation, un groupement des points représentant des échantillons dont les indices de texture possédaient des valeurs rapprochées. On a reporté les points de chacun de ces groupements dans la représentation en triangle (fig.2), en délimitant les mêmes séries de points que dans la figure 1. On a constaté qu'un certain nombre de points ne s'inscrivaient pas dans l'aire délimitée dans la figure 1. En examinant les valeurs des indices de texture, on a regroupé ces points dans d'autres cases, voisines des précédentes, si les valeurs de leurs indices de texture le permettaient. En répétant cette opération plusieurs fois, on a réussi à séparer d'une part des échantillons dont les indices de texture étaient compris entre des limites caractéristiques pour chaque classe, d'une autre, les échantillons

des mêmes classes au taux des trois fractions, sable, silt, argile, compris, eux aussi, entre des limites caractéristiques à ces classes. Les figures 1 et 2 présentent le résultat final de ces approximations successives. Sur chacune des deux

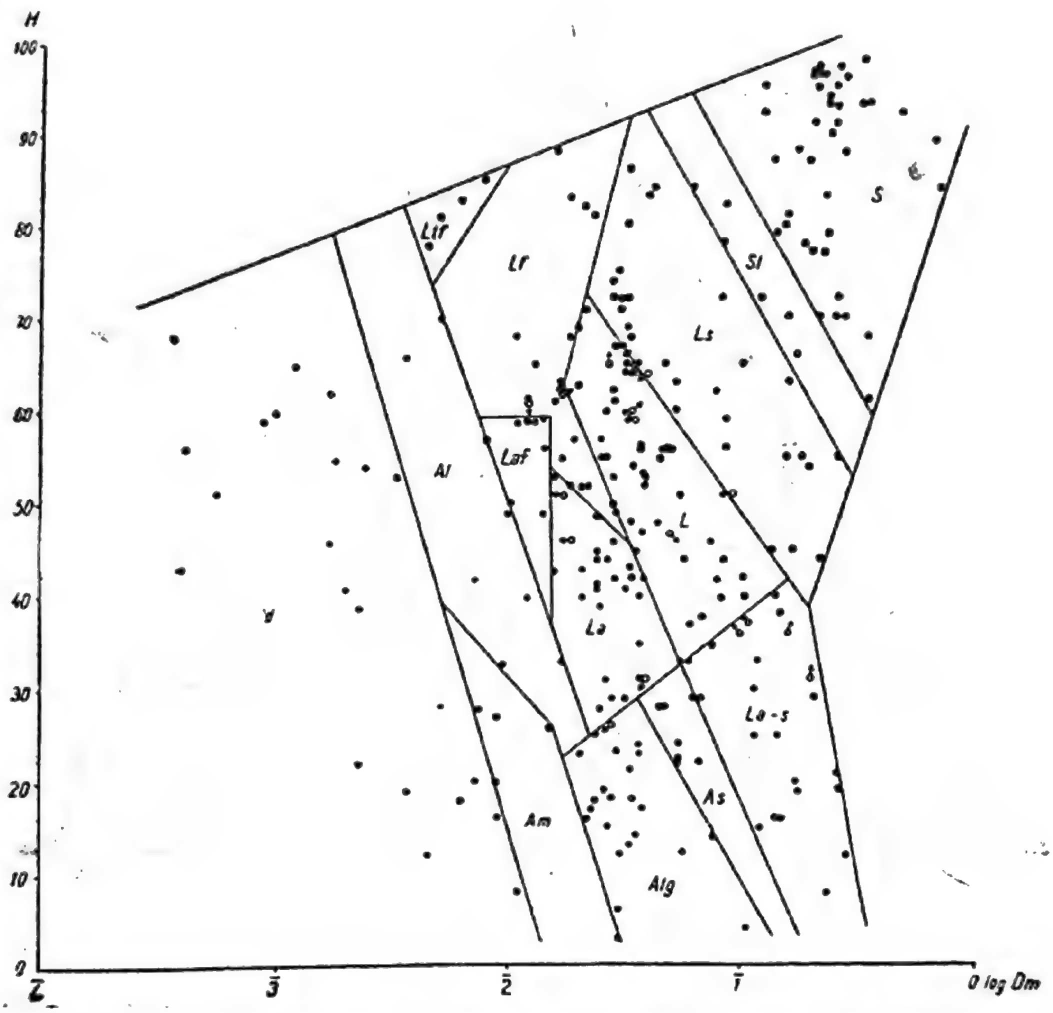

Fig. 1. Groupement en classes en fonction des indices de textu re.La concordance avec le groupement du triangle (fig. 2) est représentée par des cercles pleins. Les cercles à flèche correspondent aux échantillons qui dans le triangle sont groupés dans la case voisine, en direction indiquée par la flèche: *Al* — argile limoneuse; *Ald* — argile lourde; *Alg* — argile légère; *Am* — argile moyenne; *As* — argile sableuse; *L* — limon; *La* — limon argileux; *Laf* — limon argileux fin; *La-s* — limon argilo-sableux; *Lf* — Limon fin; *Ltf* — limon très fin; *Ls* — Limon sableux; *S* — sable; *Sl* — sable limoneux.

représentations, les points renfermés dans chaque classe représentent des échantillons à indices de texture possédant des valeurs comprises entre les limites correspondant aux échantillons groupés dans cette classe.

Il existe pourtant quelques exceptions. C'est ainsi qu'on trouve environ $6^0/_0$ des échantillons qui, d'après la valeur de leurs indices de texture sont figurés par des points inclus dans une autre classe que celle donée par leur

composition granulométrique. Ces échantillons ont été figurées par de petits cercles à flèche, dont la direction indique la classe voisine où ils sont groupés dans la triangle (fig.1). De même, dans le triangle on trouve 4⁰/₀ d'échantillons

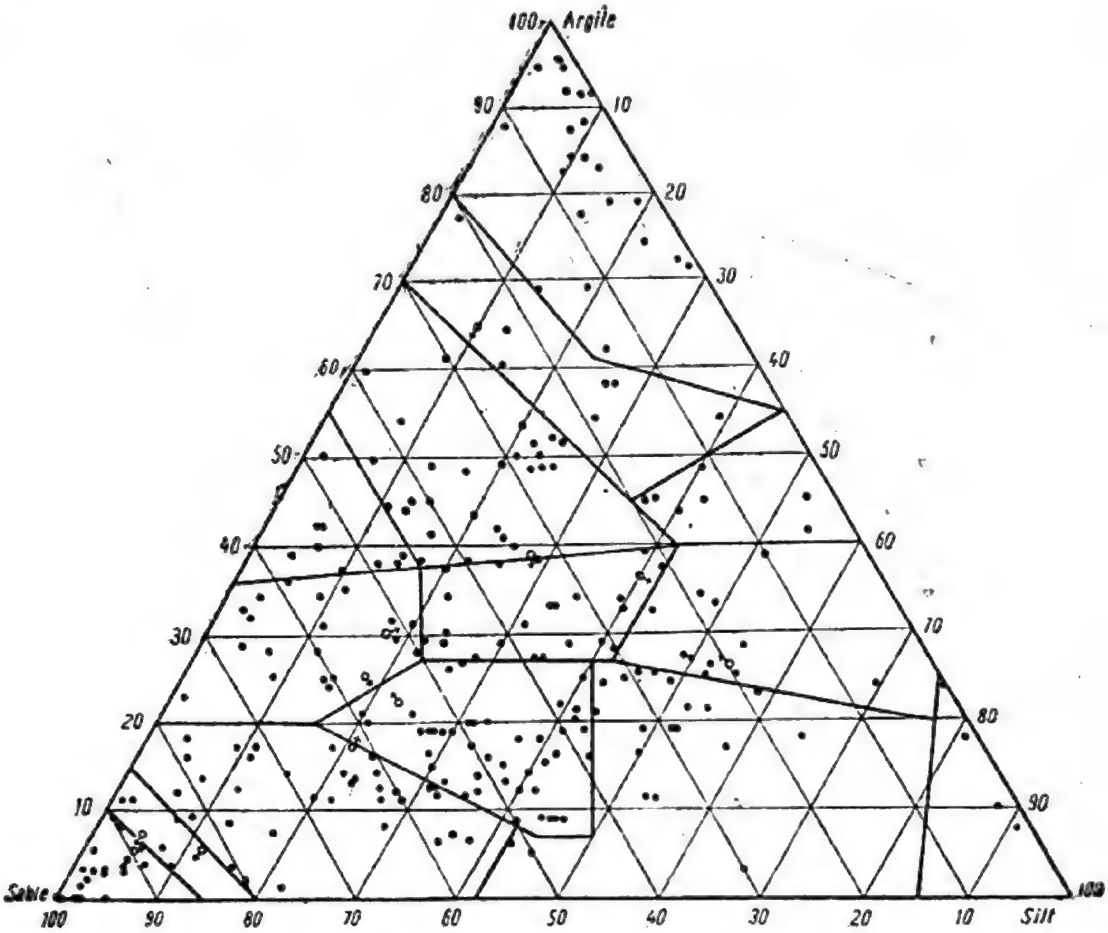

Fig. 2. Répartition des échantillons dans le triangle proposé. Les cercles pleins et à flèche représentent les cas de concordance ou non-concordance avec le groupement de la figure 1.

se trouvant entre les limites fixées pour une autre classe que celle à laquelle ils appartiennent d'après leurs indices de texture (fig.2). Le différence des taux (4 et 6⁰/₀) est due à ce que certains échantillons qui dans la figure 1 se trouvent en pleine aire de la classe, se trouvent sur le triangle sur la ligne de partage des deux classes et vice versa.

Dans la figure 3 on trouve la représentation des échantillons en fonction des indices *Dm* et *H*. Les points ont exactement les mêmes positions que dans la figure 1, mais ils sont autrement groupés en classes, celles-ci correspondant au système U.S.D.A. La corrélation entre les valeurs des indices de texture et les classes de textures est imparfaite. On trouve ici des points dont la place, d'après le triangle serait dans une case plus éloignée que la voisine (petits cercles à double flèche). Il y a plus de 16⁰/₀ de points qui se trouvent dans une autre case

que celle du triangle. Des 21 points de la case du limon, 8 y sont étrangers. Le limon fin, extrêmement bien fourni, possède beaucoup de points étrangers. L'argile sableuse n'a pu trouver une place à soi.

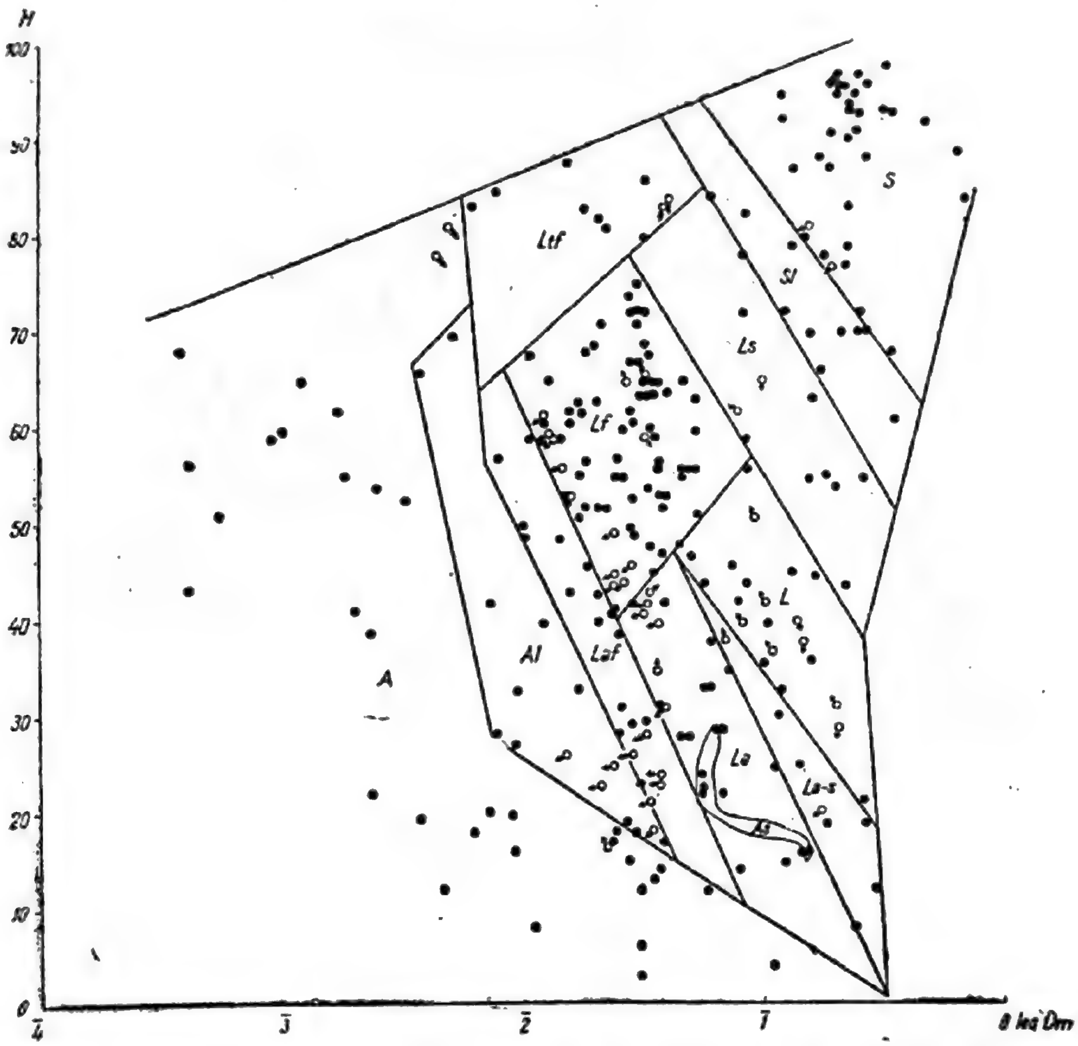

Fig. 3. Représentation en fonction des indices de texture, à groupement correspondant à la classification américaine. La position des cercles par rapport aux axes des coordonnées est identique à celle de la figure 1. Les cercles à double flèche indiquent l'appartenance, selon la classification américaine, à la deuxième case en direction de la flèche. Pour les cercles à flèche simple, voir explications de la figure 1. Pour l'explication des symboles, voir la figure 1. *Alg*, *Am*, et *Ald* sont remplacés par *A* — argile (non subdivisée).

La figure 4 représente les classes du système U.S.D.A. On peut comparer la répartition des points entre ce systéme et celui proposé par nous (fig.2).

Les classes de texture proposées par nous se trouvent dans le triangle de la figure 5, où les sommets représentent le sable (2—0,02 mm), le silt (0,02—0,002 mm) et l'argile (< 0,002 mm). On a adopté le nom des classes préconisé par. Duchaufour (1960). En première approximation, il nous a paru

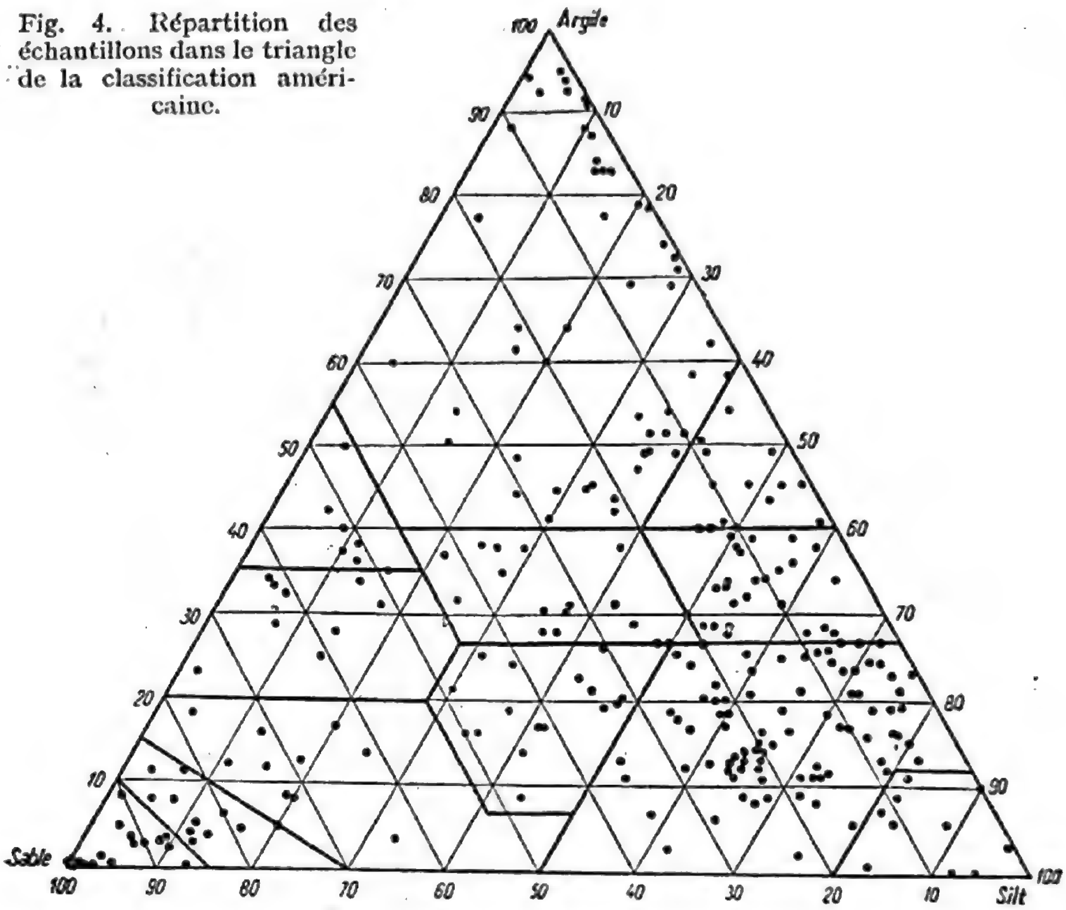

Fig. 4. Répartition des échantillons dans le triangle de la classification américaine.

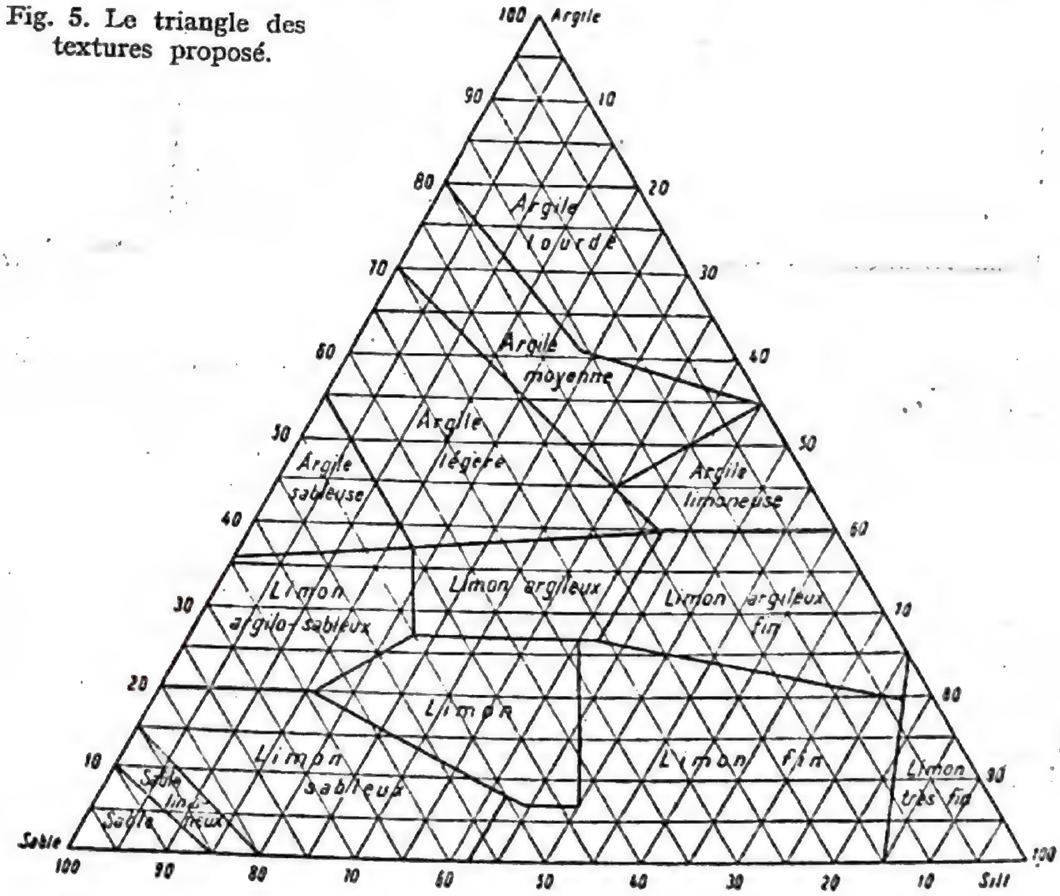

Fig. 5. Le triangle des textures proposé.

utile de distinguer, comme M. Duchaufour, une classe du limon fin argileux, mais les échantillons ainsi séparés se sont aisément répartis, d'après les indices de texture, entre le limon fin et le limon argileux fin. L'argile a été séparée par nous, au moyen des indices de texture, en argile légère, argile moyenne et argile lourde. Les limites des cases à lignes brisées, paraissent curieuses, mais une classification rationnelle ou pratique, sinon dans l'ensemble rationnelle et pratique ne pourrait satisfaire toujours l'esthétique. Nous rappelons que la classification belge du Centre de Cartographie des Sols, qui par ailleurs diffère beaucoup des deux classifications discutées par nous, emploie, outre les droites, aussi des lignes de séparation courbes, ce qui est infiniment mieux que les angles aigus (Tavernier et Maréchal, 1962).

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RÉSUMÉ

On propose une définition des classes de texture dans le système international, fondée sur les caractères spécifiques des particules, c'est-à-dire leurs dimensions. À cet effet on a choisi comme critérium l'ensemble des valeurs calculées à partir des données analytiques, les indices de texture. On s'est servi des indices de texture de l'auteur, à savoir : le diamètre moyen Dm, l'indice d'homogénéité H et le degré de finesse $F = Dm \cdot H$.

Ont été utilisées les données analytiques concernant environ 300 échantillons de sols et sédiments. Pour construire le diagramme ternaire dont les sommets représentent le sable, le silt et l'argile dans le système 2—0,02, 0,02—0,002 et <0,002 mm, on a eu recours aux indices de texture. Ceux-ci ont été représentés graphiquement, en portant en abscisse log Dm et en ordonnée H. La corrélation des points du diagramme log $Dm \cdot H$ avec les points représentant les mêmes échantillons du diagramme en triangle a conduit au groupement des points sur des aires qui ont été délimitées sur les deux diagrammes.

SUMMARY

To define the textural classes in the international system, one has to be based on the specific characters of the grains, namely on their size. For this purpose, the texture indexes, representing values deduced from the whole of the analytical data, were chosen as criteria. The author's texture indexes namely the mean diameter Dm, the homogeneity index H and a third index, the degree of fineness F as a product of the former two : $F = Dm \cdot H$ were utilized.

The analytical data of some 300 soil- and sediment samples have been used. In order to draw the ternary diagram, whose peaks represent the sand, silt and clay in the 2—0.02, 0.02—0.002, < 0.002 mm. system, reference was made to the texture indexes. These were plotted with log Dm as abscissa and H as ordinate. The correlation of the dots from the log $Dm \cdot H$ diagram, representing the same samples as those in the triangular diagram, led to a grouping of the dots in areas delimited on both diagrams.

ZUSAMMENFASSUNG

Es wird die Bestimmung der Texturklassen im internationalen System, gegründet auf den spezifischen Merkmalen der Körner, das ist auf ihren Grössen, vorgeschlagen. Zu diesem Zwecke wurde als Kriterium die Gesamtheit der aus den analytischen Angaben errechneten Werte, die Texturindexe, gewählt. Es wurden die Texturindexe des Verfassers verwendet, und zwar: Mitteldurchmesser Dm, Homogenitätsindex H und Feinheitsgrad $F = Dm \cdot H$.

Die analytischen Angaben über etwa 300 Boden- und Sedimentproben wurden dazu benutzt. Um das Ternärdiagramm aufzustellen, dessen Spitzen Sand, Schluff und Ton im System 2—0,02; 0,02—0,002 und $<0{,}002$ mm. darstellen, wurden die Texturindexe verwendet. Diese wurden graphisch dargestellt, wobei in der Abszisse log Dm und in der Ordinate H eingeschrieben wurden. Die Korrelation der Punkte aus dem Diagramm log $Dm \cdot H$ mit den dieselben Proben darstellenden Punkten aus dem Ternärdiagramm führte zur Gruppierung der Punkte in Flächen, welche auf den beiden Diagrammen abgegrenzt wurden.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 34

A NEW CRITERION FOR SELECTING SOIL SEPARATE SIZE LIMITS

A. CANARACHE, E. MOȚOC [1]

Problems concerning soil mechanical analysis and soil texture classification have been dealt with by the International Soil Science Society since its establishment. Although one of the aims of the foundation of the I.S.S.S. First Commission was the unification of the determination and interpretation methods, an international agreement to be observed in most countries could not be achieved.

There are many explanations for this situation. The dispersion methods and soil separates classifications used by various authors are different. Moreover, it is difficult to have an objective criterion for evaluating the superiority of one or another of the soil separate classifications. The physical and chemical properties of soil separates (Atterberg, 1912; Kocerina, 1954), and texture evaluation by feeling (Shaw, 1935; *Soil Survey Manual*, 1951) have been used as such criterions. The use of texture triangles in which lines of equal value for some physical properties are drawn (Franzmeier, Whiteside and Erickson, 1960; Turnbull and Knight, 1961), or of the correlations between physical properties and texture indices (Hutchinson and Townsend, 1961) is also possible.

This paper is based on the hypothesis (premise) that, for the restricted target of evaluating the size limits of the soil separates optimum for a quantitative characterization of soil texture, the strength of the correlations between various pairs of soil separates could serve as such an objective criterion.

MATERIAL AND METHODS

Results from the mechanical analyses of some 300 soil samples, differing in respect of the soil forming material, the soil genetical group and the depth of sampling (the soil horizon) were used. Sample treatment was performed according to Katchinski's method, previously checked for achieving an adequate dispersion (Moțoc, 1959). This method includes percolation with 0.05 n hydrochloric acid, peptization with natrium hydroxide and boiling. Soil separates over 0.2 mm and over 0.1 mm were separated by sieving, and those under 0.05 mm, under 0.02 mm, under 0.01 mm, under 0.005 mm, under 0.002 mm and under 0.001 mm by pipeting; the 0.1—0.05 mm soil separate content was

[1] Central Research Institute for Agriculture, Bucharest, RUMANIAN PEOPLE'S REPUBLIC.

calculated. Results were expressed on a 100 g carbonate-free oven-dry soil basis. The determined soil separates permitted to fit the analysed soil samples in textural classes according to the following classifications: Chiriță-Burt's (1955) (based on Atterbergs's (1912) soil separates), USDA (*Soil Survey Manual*, 1951) and Katchinski's (1958).

The results were plotted, by pairs of separates, on rectangular coordinates, and the regression equations (linear) and correlation coefficients were calculated. In appreciating these results, it was thought that high correlations indicated soil separates not worth while to be determined for the quantitative characterization of soil texture; on the contrary, low corelation coefficients were thought to denote characteristic soil separates, whose determination would permit a good classification of soil texture. A second appreciation was founded on the identification, based on genetical criterions, of 3 soil sample groups: those originating from clay and clay-loam soil forming materials, from loess soil forming materials, and from loam, sandy loam and sand soil forming materials. The possibility offered by various soil separate correlations for differentiating these sample groups was used as criterion for appreciating the usefulness of determining those various soil separates.

Some soil physical properties were determined on the same soil samples: hygroscopic coefficient (Mitscherlich's method), maximum molecular water capacity (according to Lebedev), moisture equivalent (Briggs and Mc. Lane), lower and upper plastic limits as well as plasticity index (Casagrande's methods). Simple and multiple correlations were calculated between these physical properties and various soil separates.

RESULTS AND DISCUSSIONS

The size-limit between clay and silt varies, according to different authors from 0.001 to 0.01 mm. Correlations between pairs of clay fractions defined according to these various size-limits (items 1—5 in table 1) were high, and the possibilities of differentiating the 3 sample groups (items 1—5 in table 2) were low. It seems that, during the development of the parent material and the soil, a regular size distribution of the fine soil separates is achieved. For a quantitative characterization of soil texture, any of the above clay fractions could equally be used.

The size-limit between silt and sand is considered by various authors as 0.02 or 0.05 mm. The 0.05 mm size-limit offered better possibilities for texture characterization as compared to the 0.02 one. This could be inferred from the lower correlation coefficients, as well as from the better differentiation of the 3 sample groups, in the following correlations: clay versus clay+silt (items 6—9 in tables 1 and 2, figure 1); between various silt fractions (items 10—11 in tables 1 and 2, figure 2); betweem various sand fractions (item 12 in tables 1 and 2); between various soil separates of the different texture classifications (clay versus silt — items 13, 16, 19 and 20 in tabels 1 and 3; clay versus sand — items 14, 17 and 21 in tables 1 and 2, figure 3; silt versus sand — items 23 and 24 in tables 1 and 2, figure 4). The choosing of one of these two silt-sand size-limits is therefore no more an indifferent question.

Table 1

Correlations between various soil separates for all 300 soil samples

No.	Correlations between	Correlated soil separates x	Correlated soil separates y	Regression equation	Correlation coefficient
1	Various clay fractions	<0.001	<0.002	$y=1+1.09x$	+0.988
2		<0.001	<0.005	$y=4+1.22x$	+0.973
3		<0.001	<0.01	$y=8+1.28x$	+0.941
4		<0.002	<0.005	$y=2+1.12x$	+0.992
5		<0.002	<0.01	$y=6+1.20x$	+0.977
6	Clay versus clay+silt	<0.001	<0.02	$y=20+1.30x$	+0.903
7		<0.001	<0.05	$y=53+0.84x$	+0.614
8		<0.002	<0.02	$y=18+1.19x$	+0.920
9		<0.002	<0.05	$y=53+0.77x$	+0,623
10	Various silt fractions	0.002—0.02	0.002—0.05	$y=16+1.20x$	+0,611
11		0.001—0.05	0.002—0.05	$y=-3+0.98x$	+0.974
12	Various sand fractions	>0.02	>0.05	$y=-12+0.78x$	+0.800
13	Various Atterberg's soil separates	<0.002	0.002—0.02	$y=19+0.17x$	+0.332
14		<0.002	>0.02	$y=81-1.16x$	—0.925
15		0.002—0.02	>0.02	$y=82-1.66x$	—0.660
16	Various USDA soils separates	<0.002	0.002—0.05	$y=53-0.22x$	—0.226
17		<0.002	>0.05	$y=47-0.78x$	—0.626
18		0.002—0.05	>0.05	$y=56-0.77x$	—0.616
19	Various Katchinski's soil separates	<0.001	0.001—0.01	$y=8+0.29x$	+0.590
20		<0.001	0.01 —0.05	$y=44-0.42x$	—0.387
21		<0.001	>0.05	$y=46-0.85x$	—0.618
22		0.001—0.01	0.01 —0.05	$y=41-0.56x$	—0.255
23		0.001—0.01	>0.05	$y=50-1.75x$	—0.615
24		0.01 —0.05	>0.05	$y=37-0.50x$	—0.397

From the above facts it may be concluded that the soil separates classifications using 0.05 mm as size-limit between silt and sand (USDA and Katchinski's classifications) are better than Atterberg's classification. Using the latter, only a single correlation (silt versus sand, figure 4a) permited the differentiation of the 3 sample groups (and only of one of them). Using the former classifications, many correlations (figures 1b, 2b, 3b and 4b) permitted the differentiation of all 3 sample groups. As for Katchinski's classification, which divides silt into fine+medium and coarse, it is the coarse silt that appeared to be characteristic (see items 19 and 23, as compared to 20 and 24, in tables 1 and 2).

The 3 sample groups have been separated especially on the basis of the texture and the geological age of the parent material. Due to soil forming processes, the texture of some of the samples (belonging to certain genetical horizons) has been entirely transformed, resulting in a coarser texture (including

Table 2

Correlations between various soil separates for each of the 3 soil sample groups

No.	Correlations between:	Correlated soil separates: x	Correlated soil separates: y	Clay and clay loam soil forming materials: Regression equation	Clay and clay loam soil forming materials: Correlation coefficient	Loess soil forming materials: Regression equation	Loess soil forming materials: Correlation coefficient	Loam, sandy loam and sand soil forming materials: Regression equation	Loam, sandy loam and sand soil forming materials: Correlation coefficient
1	Various clay fractions	<0.001	<0.002	$y=3+1.07x$	+0.977	$y=5+0.95x$	+0.936	$y=2+1.07x$	+0.978
2		<0.001	<0.005	$y=9+1.11x$	+0.944	$y=8+1.04x$	+0.932	$y=2+1.24x$	+0.976
3		<0.001	<0.01	$y=23+0.98x$	+0.854	$y=10+1.21x$	+0.888	$y=3+1.40x$	+0.974
4		<0.002	<0.005	$y=5+1.06x$	+0.993	$y=6+0.99x$	+0.899	$y=0+1.14x$	+0.986
5		<0.002	<0.01	$y=16+1.01x$	+0.958	$y=6+1.22x$	+0.906	$y=2+1.29x$	+0.986
6	Clay versus clay+silt	<0.001	<0.02	$y=38+0.89x$	+0.800	$y=24+1.21x$	+0.837	$y=7+1.63x$	+0.950
7		<0.001	<0.05	$y=68+0.45x$	+0.671	$y=79+0.42x$	+0.343	$y=19+1.95x$	+0.867
8		<0.002	<0.02	$y=31+0.93x$	+0.840	$y=19+1.26x$	+0.910	$y=5+1.49x$	+0.956
9		<0.002	<0.05	$y=65+0.46x$	+0.687	$y=77+0.43x$	+0.345	$y=17+1.79x$	+0.877
10	Various silt fractions	0.002—0.02	0.002—0.05	$y=3+1.30x$	+0.715	$y=43+0.73x$	+0.437	$y=5+1.77x$	+0.901
11		0.001—0.05	0.002—0.05	$y=5+0.99x$	+0.843	$y=4+0.88x$	+0.943	$y=0+0.94x$	+0.977
12	Various sand fractions	>0.02	>0.05	$y=3+0.62x$	+0.838	$y=15+0.56x$	+0.640	$y=34+1.26x$	+0.953
13	Various Atterberg's soil separates	<0.002	0.002—0.02	$y=40-0.25x$	−0.571	$y=18+0.29x$	+0.352	$y=3+0.57x$	+0.923
14		<0.002	>0.02	$y=60-0.75x$	−0.898	$y=81-1.25x$	−0.884	$y=95-1.49x$	−0.956
15		0.002—0.02	>0.02	$y=17+0.28x$	+0.149	$y=87-1.50x$	−0.772	$y=96-2.18x$	−0.903
16	Various USDA soil separates	<0.002	0.002—0.05	$y=64-0.50x$	−0.623	$y=75-0.50x$	−0.406	$y=17+0.78x$	+0.617
17		<0.002	>0.05	$y=33-0.43x$	−0.693	$y=28-0.61x$	−0.498	$y=83-1.79x$	−0.873
18		0.002—0.05	>0.05	$y=10+0.07x$	+0.094	$y=54-0.69x$	−0.681	$y=93-1.49x$	−0.918
19	Various Kacinski's soil separates	<0.001	0.001—0.01	$y=21+0.02x$	+0.049	$y=11+0.17x$	+0.269	$y=3+0.40x$	+0.804
20		<0.001	0.01—0.05	$y=46-0.55x$	−0.687	$y=62-0.54x$	−0.294	$y=15+0.53x$	+0.486
21		<0.001	>0.05	$y=32-0.46x$	−0.675	$y=21-0.42x$	−0.339	$y=82-1.96x$	−0.868
22		0.001—0.01	0.01—0.05	$y=37-0.59x$	−0.487	$y=89-2.66x$	−0.914	$y=10+1.37x$	+0.615
23		0.001—0.01	>0.05	$y=22-0.42x$	−0.338	$y=27-1.03x$	−0.518	$y=89-4.16x$	−0.906
24		0.01 —0.05	>0.05	$y=9+0.19x$	+0.228	$y=28-0.33x$	−0.489	$y=85-1.69x$	−0.820

sandy loams) for some of the first group samples, and in a finer one (including clay-loams) for some of the third group samples. Soil profiles were well individualized in the plotting system used (fig. 5), soil samples belonging to different horizons of one and the same soil profile being located along a characteristic straight line. The 3 sample groups were thus well defined units, not to be confounded with groups differentiated according to their clay content only.

A better possibility for differentiating the analysed soil samples when using the 0.05 mm silt-sand size-limit also resulted from the texture triangles (figure 6). Soil samples covered better the triangle than when using the 0.02 mm limit, and a better possibility for differentiating the 3 sample groups was also offered.

Besides the above considerations on size-limit selection for soil separates, the analytical data and the calculations presented in this paper enabled us to prepare special tables for comparing soil textural classes as proposed by various authors (Canarache, 1965).

In table 3 corelation coefficients (simple and multiple) are presented between soil separates and some physical properties of the same soil samples. Simple correlation coefficients between various clay fractions and soil physical properties were high and not too different for the various size-limits of the clay fraction; this corroborated with the above mentioned conclusions about the equal value of the different size-limits. There was however a certain tendency for the correlations of the 0.002 mm clay fraction to be somewhat higher than those of the other fractions.

The calculated multiple correlations presented R values approaching the above simple correlation coefficients. Due to the well-known effect of the clay

Table 3

Correlation coefficients between soil separates and some physical soil properties

Soil separates	Physical soil properties					
	Hygroscopic coefficient	Maximum molecular water capacity	Moisture equivalent	Lower plastic limit	Upper plastic limit	Plasticity index
Simple correlations between clay fractions and soil properties						
<0.001 mm	+0.946	+0.900	+0.862	+0.605	+0.866	+0.860
<0.002 mm	+0.951	+0.921	+0.945	+0.640	+0.880	+0.893
<0.005 mm	+0.919	+0.940	+0.946	+0.649	+0.886	+0.830
<0.01 mm	+0.924	+0.945	+0.965	+0.625	+0.880	+0.805
Multiple correlations between soil separates within various classification systems and soil properties						
Atterberg's soil separates	0.902	0.903	0.904	0.678	0.885	0.832
USDA soil separates	0.925	0.917	0.923	0.682	0.875	0.771
Kacinski's soil separates	0.952	0.910	0.925	0.702	0.885	0.848

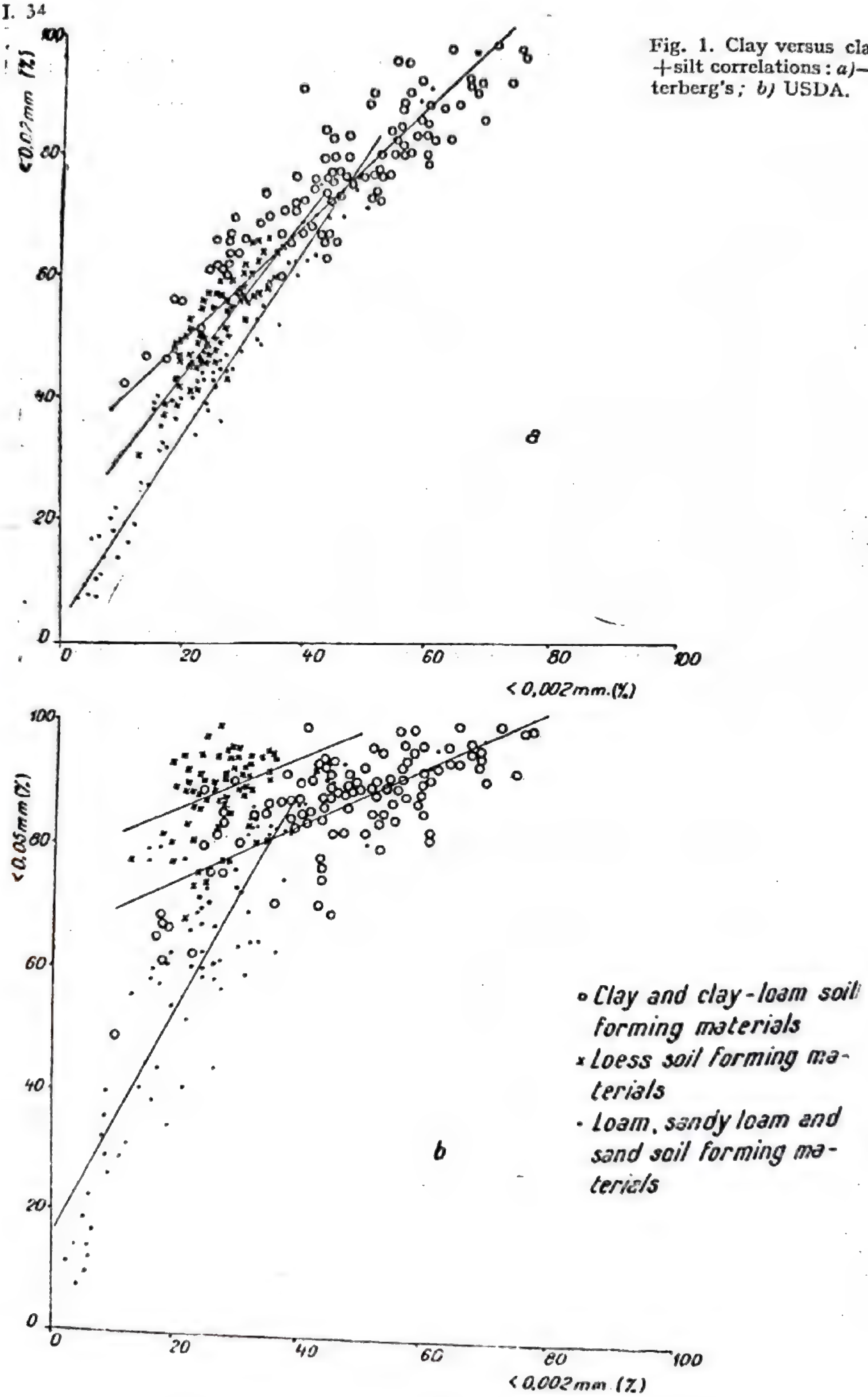
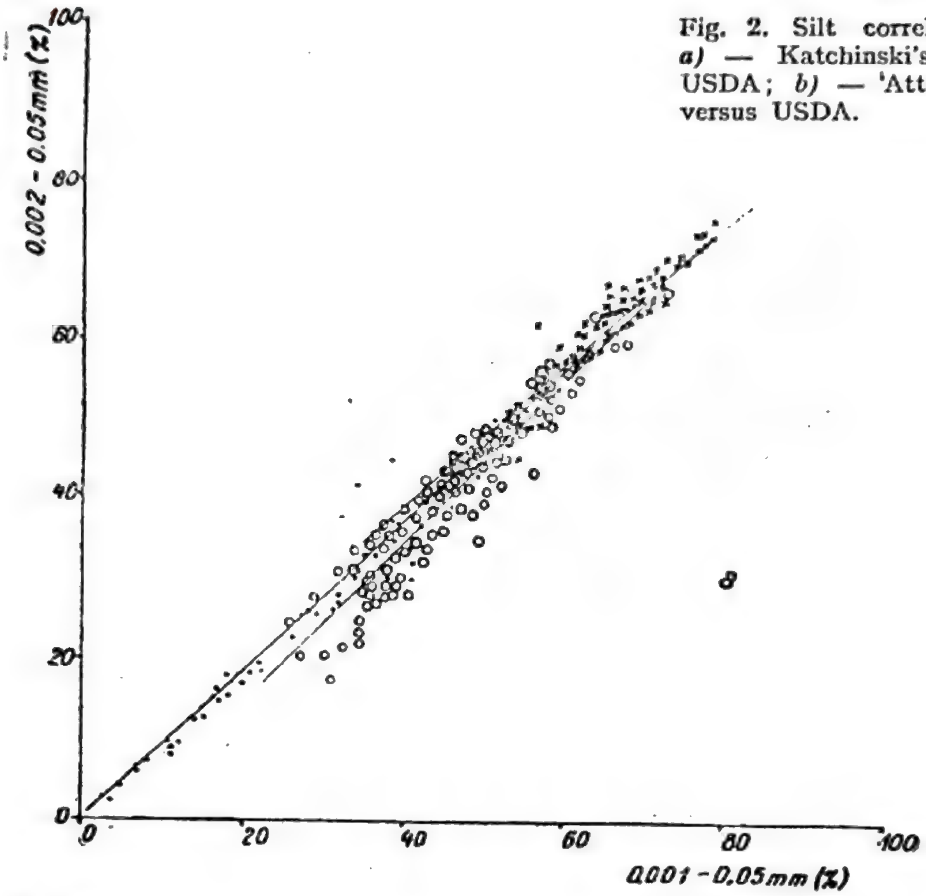


Fig. 1. Clay versus clay + +silt correlations: *a)*— Atterberg's; *b)* USDA.

Fig. 2. Silt correlations: *a)* — Katchinski's versus USDA; *b)* — Atterberg's versus USDA.



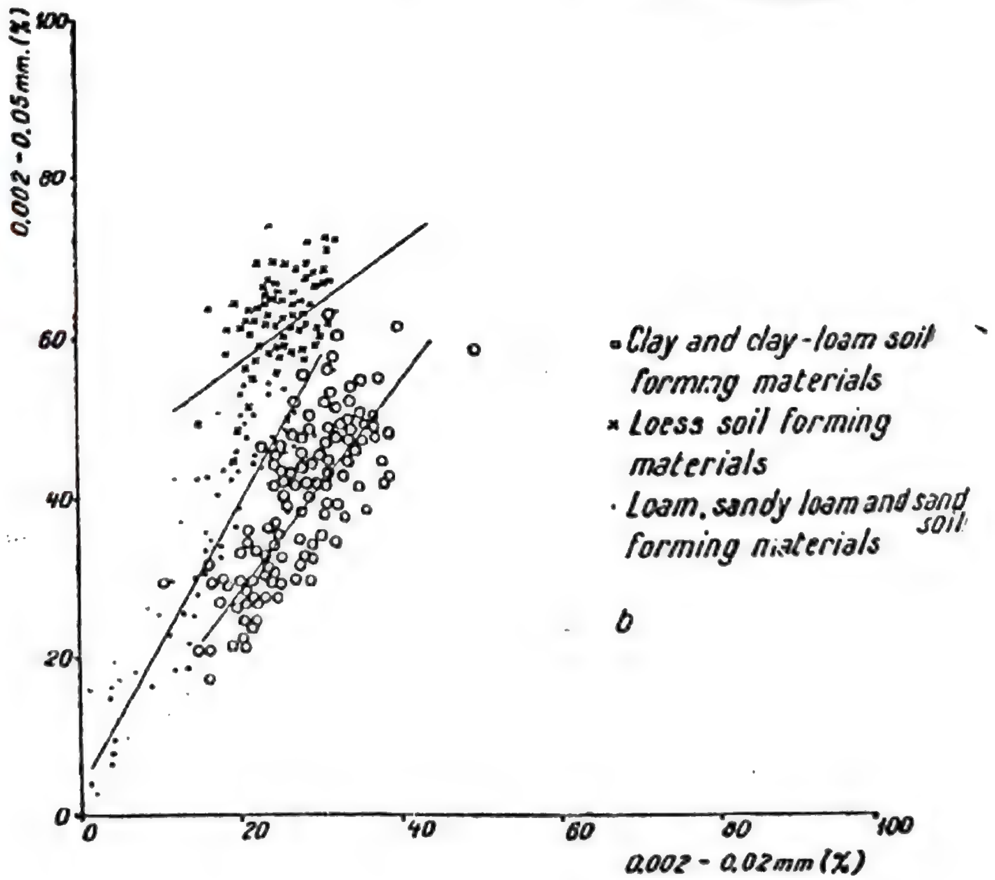


Fig. 3. Clay versus sand correlations: *a)* — Atterberg's; *b)* — USDA.

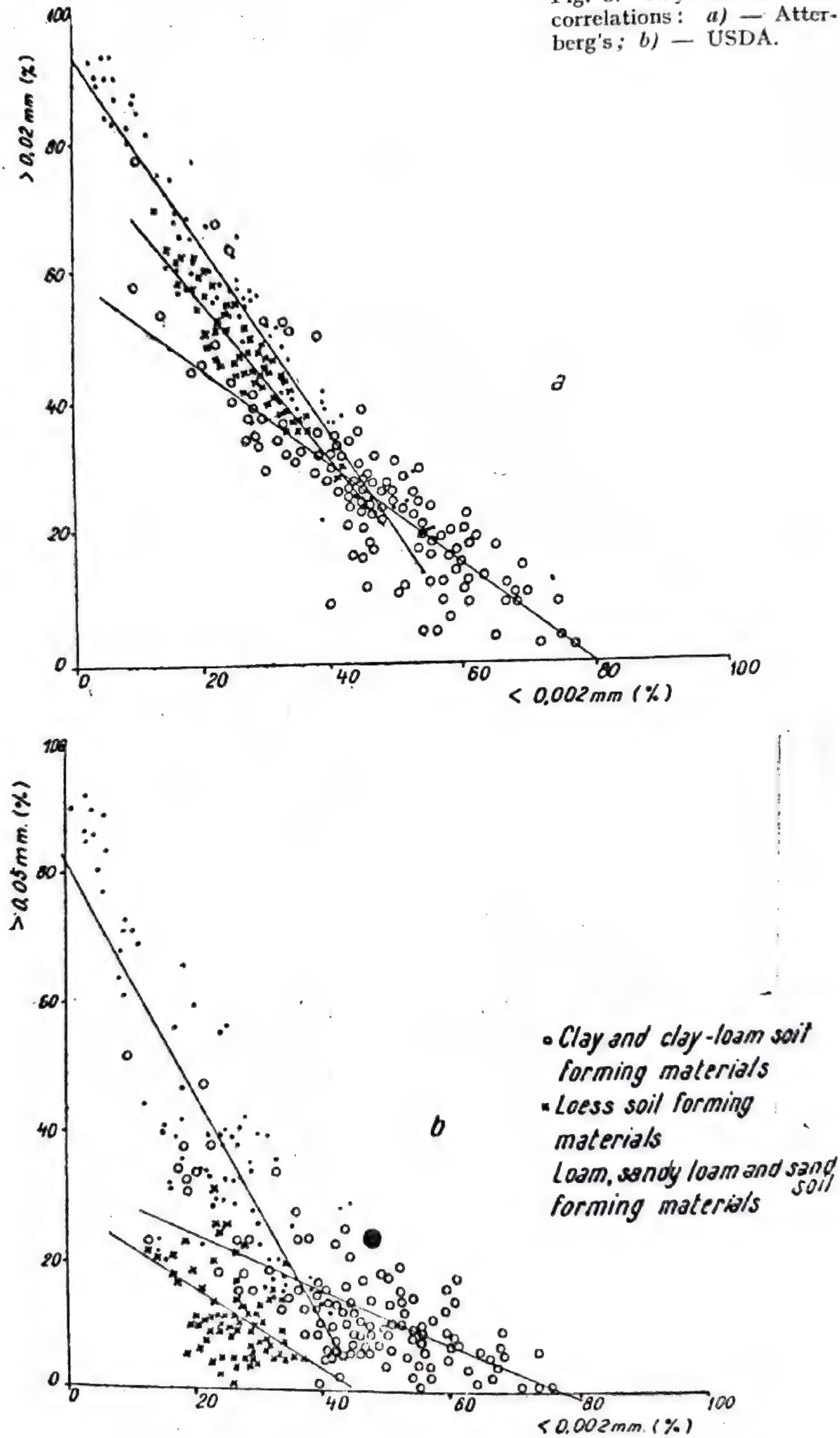
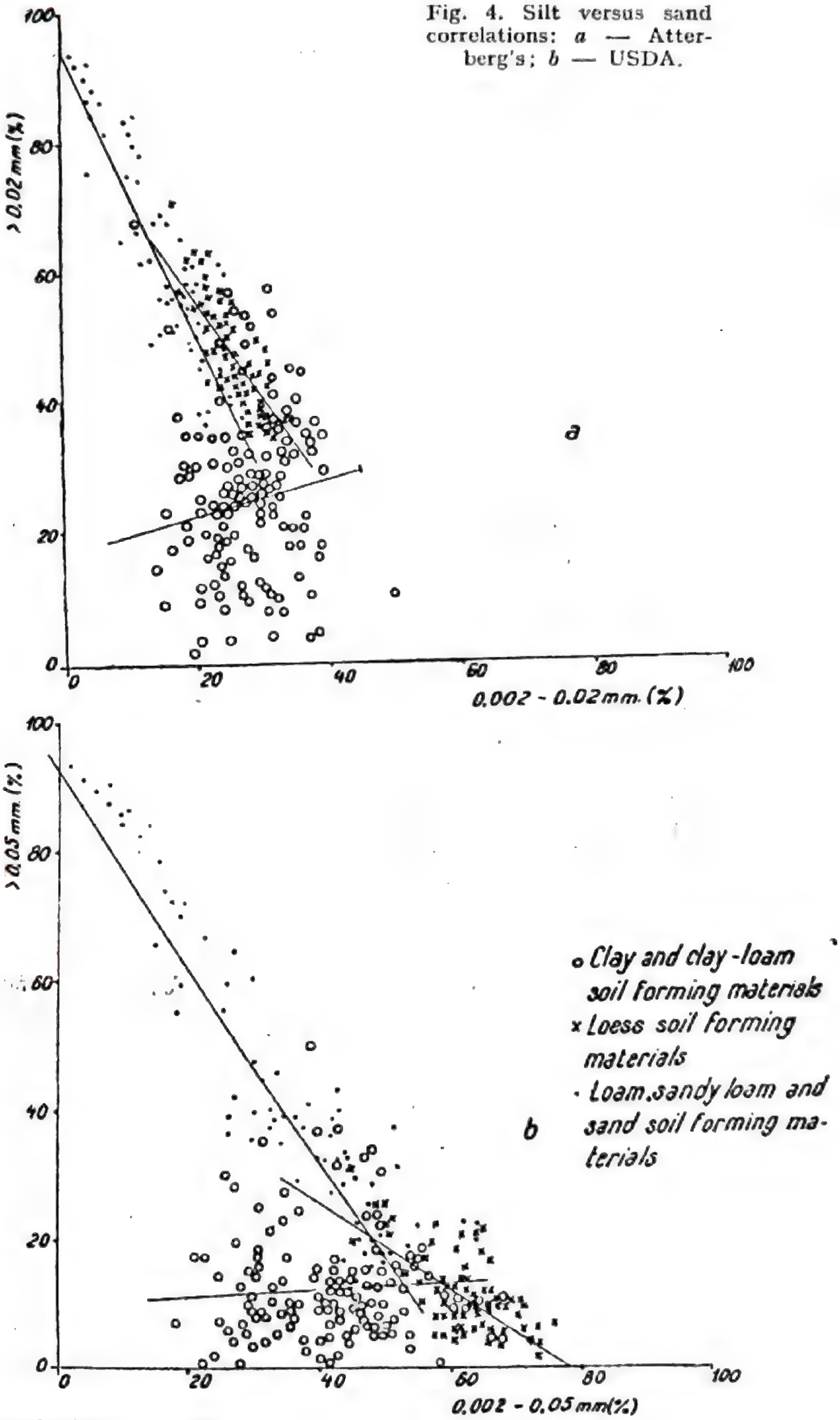


Fig. 4. Silt versus sand correlations: *a* — Atterberg's; *b* — USDA.



content on these physical properties and to the relationships between the clay content and the content in the other soil separates, as discussed in this paper, this criterion seems to be inadequate for evaluating soil separate size limits. For the same reasons, it seems useless to calculate such multiple correla-

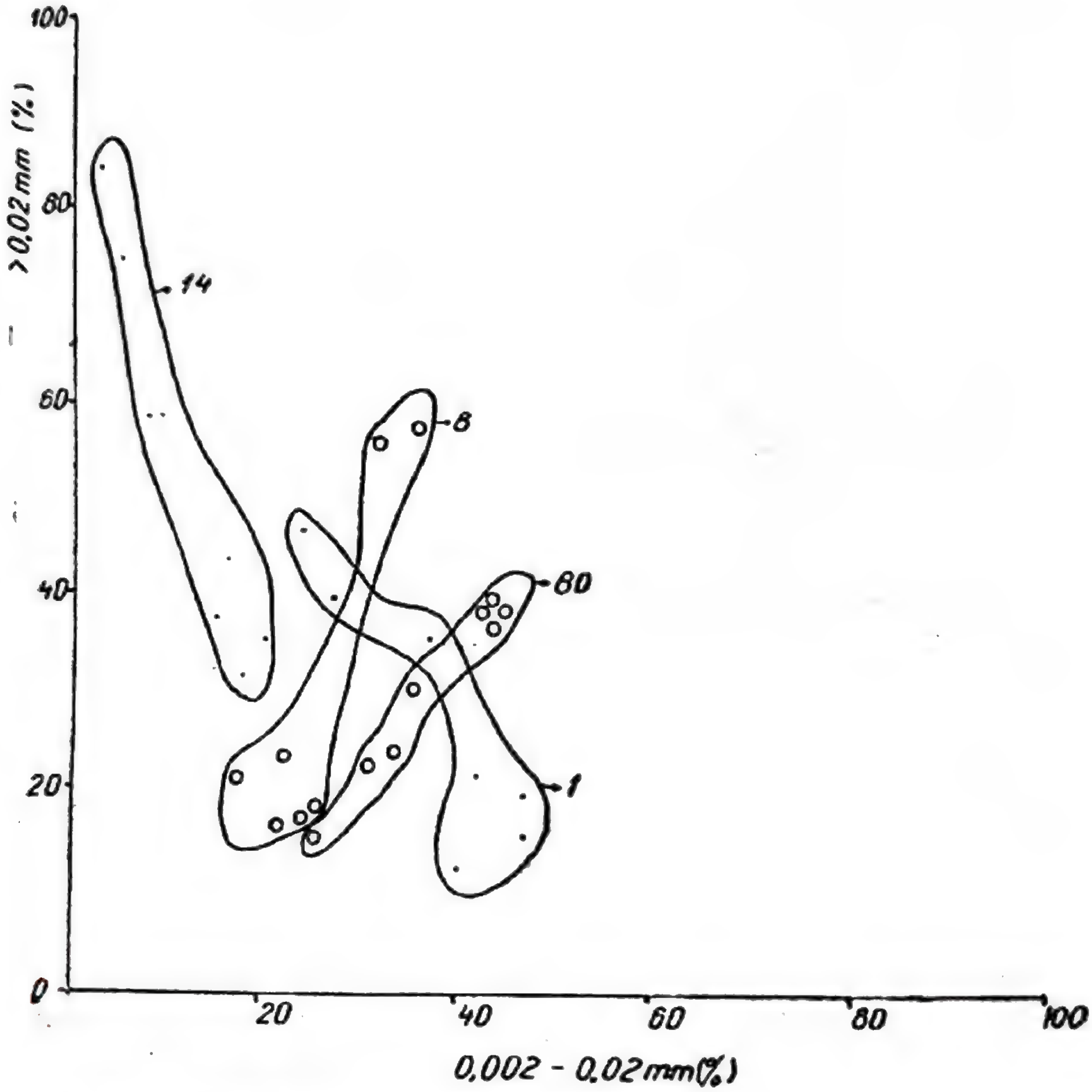


Fig. 5. Atterberg's silt versus sand correlation for some soil profiles of the american 7th Approximation (numbers refer to numbers of soil profiles).

tions for indirect estimation of the soil physical properties. A certain improvement, as compared to simple correlations, in the degree of determination was only noticeable for the lower plastic limit, which in fact presented the lowest correlation coefficients. Among the different soil separates classifications, Katchinski's led to R values somewhat higher as compared to the other classifications.

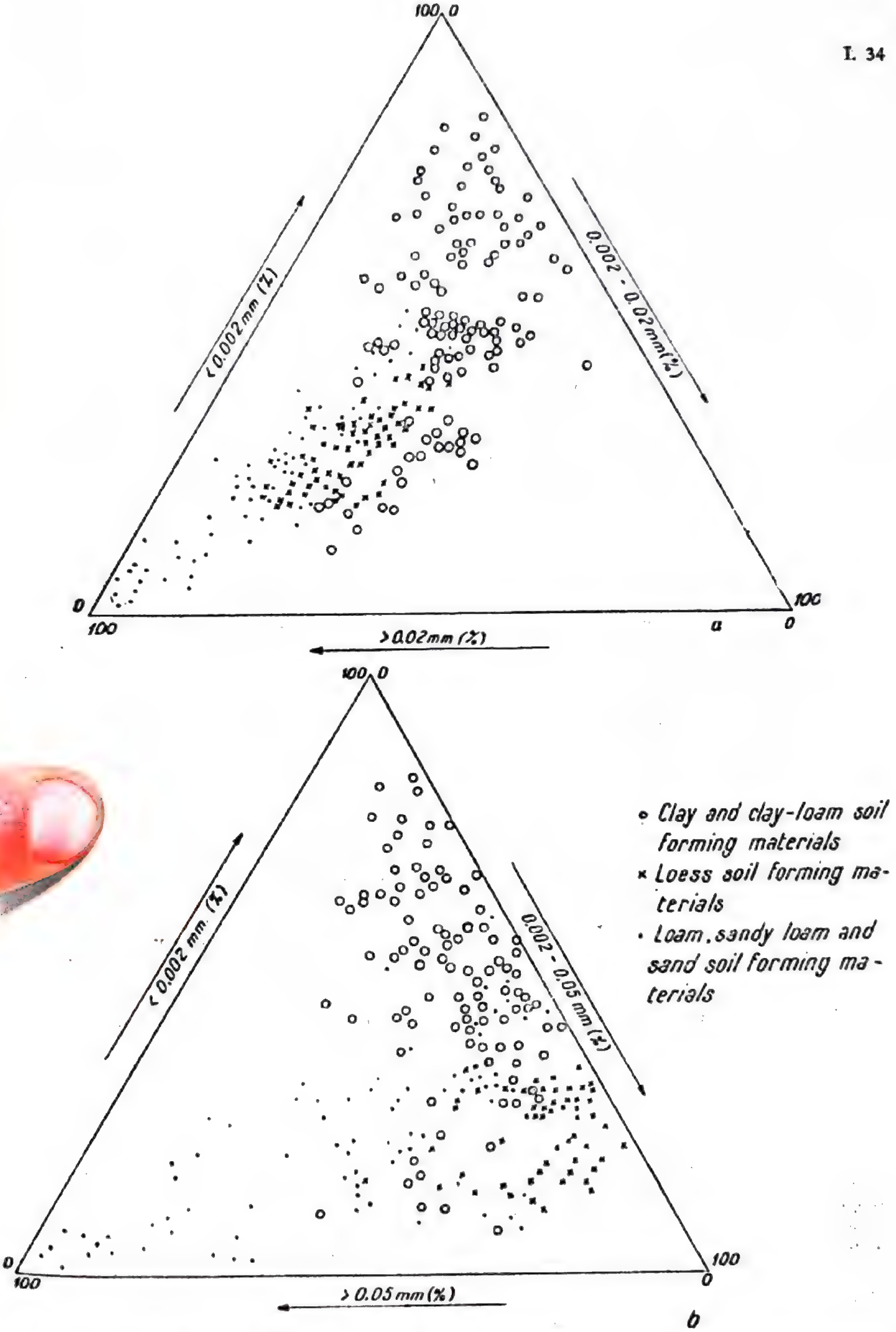


Fig. 6. Plotting of the 3 soil sample groups in soil texture diagrams: *a* — Atterberg's soil separates; *b* — USDA soil separates.

CONCLUSIONS

1. The method of plotting the content of various soil separates by pairs represents an objective criterion that can be successfully used for selecting, in view of a quantitative characterization of the soil textural classes, the size-limits of the soil separates.

2. For the quantitative characterization of the soil textural classes, as inferred from this method, the clay-silt size-limit can equally be fixed at 0.001, 0.002, 0.005 mm and even 0.01 mm. The silt-sand size-limit of 0.05 mm is more suitable and permits a better differentiation of the soil textural classes than the 0.02 mm one.

3. The method of plotting the content of the various soil separates by pairs also offers the possibility of differentiating certain sample groups. Each of them originated from a certain type of parent material and preserved some common characteristics, even if the texture of some of the samples had been seriously altered during the soil forming process. Data in this paper permitted to differentiate such 3 sample groups.

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SUMMARY

The paper is based on the hypothesis that, for the restricted target of optimum evaluation the size-limits of the soil separates for a quantitative characterization of soil texture, the strength of the correlations between various pairs of soil separates and the possibilities offered by such correlations for differentiating certain sample groups could serve as objective criterions. These criterions led to the conclusion that clay-silt size-limit could be equally fixed at 0.001,

0.002,0.005 mm and even 0.01 mm, while the silt-sand size-limit of 0.05 mm was more suitable than the 0.02 one. 3 sample groups have been differentiated, each of them originating from a certain type of parent material and conserving certain common characteristics, even if the texture of some of the samples had been seriously altered during the soil forming process.

RÉSUMÉ

L'ouvrage est basé sur l'hypothèse que pour l'objectif limité de l'évaluation des dimensions optimum des fractions granulométriques du sol en vue d'une caractérisation quantitative de la texture du sol, le caractère plus ou moins serré des corrélations entre les différentes paires de fractions granulométriques et les possibilités offertes par de telles corrélations pour différencier certains groupes d'échantillons pourraient servir comme critères objectifs. Ces critères mènent à la conclusion que la limite de dimension argile-limon pourrait être également fixée à 0,001,0,002, 0,005 mm et même 0,01 mm, tandis que la limite de dimension limon-sable de 0,05 mm est plus adéquate que celle de 0,02. Trois groupes d'échantillons ont été différenciés, chacun d'eux dérivant d'un certain type de materiel parental et conservant certaines caractéristiques communes, même si la texture de quelques-uns des échantillons aient été sérieusement altérés pendant le processus pédogénétique.

ZUSAMMENFASSUNG

Die Abhandlung ist auf der Hypothese begründet, dass für das beschränkte Ziel der optimalen Schätzung von Grössengrenzen zwischen granulometrischen Fraktionen hinsichtlich einer quantitiven Charakterisierung der Bodentextur, die enge Korrelation zwischen verschiedenen Fraktionen und die von solchen Korrelationen angebotenen Möglichkeiten um gewisse Bodenprobengruppen zu differenzieren, wohl als objektive Kriterien dienen könnten. Diese Kriterien führten zu der Schlussfolgerung dass die Ton-Schluff Grössengrenze gleichfalls an 0,001,0,002,0,005 mm und sogar an 0,01 mm während die Schluff-Sand Grössengrenze an 0,05 mm anstatt an 0,02 mm, fixiert werden könnte. Drei Bodenprobengruppen sind differenziert worden, jede von ihnen von einem bestimmten Typus von Muttergestein abstammend und gewisse gemeinsame Merkmale beibehaltend, sogar wenn die Textur einiger Bodenproben ernstlich durch den Bodenbildungsprozess verändert wurde.

APPLICATION DU COEFFICIENT D'HYGROSCOPICITÉ DE KURON COMME COMPLÉMENT ET REMPLAÇANT DE L'ANALYSE MÉCANIQUE

MARIAN P. NEMEŞ, EMERIC BALINT[1]

L'analyse mécanique — dont l'importance dans l'étude des sols et des sédiments est bien connue — rend possible la connaissance avancée de leur degré de dispersion, par la séparation de la matière minérale en catégories de particules entre certaines limites.

Les données de cette analyse ne permettent pas une certe différenciation des sols du point de vue des conséquences de leur degré de dispersion pour leurs propriétés physiques et physico-chimiques (consistance, stabilité de la structure, capacité d'absorption d'eau et des éléments nutritifs etc.). On attribue une importance fondamentale à la grandeur de la fraction argileuse $< 2\mu$, mais l'influence de cette fraction peut être très différente, en fonction des rapports d'autres fractions et surtout de la quantité des particules d'ordre colloïdal et de la nature minéralogique de l'argile.

Pour la différenciation rapide des sols du point de vue des effets physiques et physico-chimiques déterminés par leur état de dispersion et la nature minéralogique de la fraction minérale colloïdale — donc pour une meilleure interprétation globale des résultats de l'analyse mécanique — il paraît nécessaire d'utilisier comme complément une grandeur physique ayant le caractère d'expression résultante des effets cumulés de ces deux caractères déterminants mentionnés.

Une telle grandeur physique, expression de la surface totale des particules du sol et de leur capacité d'adsorption, est le coefficient d'hygroscopicité de Kuron, dont la détermination est plus commode que celle du coefficient d'hygroscopicité maxime d'après Mitscherlich (Mados, 1939).

Nous avons fait de nombreuses recherches concernant la valeur indicatrice du coefficient de Kuron pour :

a) l'expression des différences dans les propriétés d'adsorption de la fraction $< 2\ \mu$, isollée de différents minéraux et sols (différences causées par la grandeur de la surface active et par la nature minéralogique des particules $< 2\mu$) ;

b) l'expression de la variation parallèle de la valeur du coefficient de Kuron et d'une série de propriétés physiques et physico-chimiques des sols, déterminées par les deux caractères mentionnés ci-dessus ;

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c) l'expression du parallélisme entre les valeurs du coefficient d'hygroscopicité de Kuron et les espèces texturales des sols, déterminées par l'analyse mécanique et par la palpation.

MÉTHODE DE TRAVAIL ET RÉSULTATS

Dans ces recherches on a employé la fraction inferieure à 2 μ isolée des roches, minéraux et sols différents, saturée en ions d'hydrogène. La séparation du matériel a été faite par sédimentation après quoi celui-ci a été saturé en ions d'hydrogène, utilisant pour cela l'acide acétique. Des sols naturels ont été utilisés aussi. On a determiné les caractéristiques physiques, chimiques et biologiques suivantes : la valeur „hy" (déterminée d'après Kuron, modifiée par Csapó et Nemeş, 1953) ; la valeur T (en vertu de l'adsorption de NH_4, Cernescu, 1939) ; l'adhérence (avec la balance Katchinski, cité par Vorobiov et collab. 1953 ; Canarache et Florescu, 1963) ; la stabilité mécanique des agrégats (avec la balance POP, cité par Csapó et Balint, 1958) ; l'analyse mécanique (par la méthode STAS — Standard d'État — 1024-50 ; la combinaison de la méthode Atterberg avec la méthode à la pipette) ; l'eau morte (par la méthode Dolgov, cité par Chiriță, 1955), en utilisant le suivant procédé avec les modifications apportées par nous dans les expériences avec les minéraux argileux : addition d'une solution nutritive à la fraction minérale inferieure à 2 μ et mélange à l'aide d'une baguette de verre, réalisant ainsi une structure artificielle ; le milieu obtenu a été ensemencé avec du blé, en couvrant la surface avec une couche de sable. Pour établir les constantes de l'équation Freundlich-Kuron (citée par Di Gleria et al., 1957 ; Rodé, 1952 ; Blanck, 1939) nous avons employé H_2SO_4 — 54, 60, 70, 74%.

Les résultats et leur interprétation (tableaux 1—4 et figures 1—2). Les différences de la valeur „hy" qui surviennent entre les diverses substances peuvent être expliquées—comme nous l'avons précisé antérieurement—par les différences en ce qui concerne la grandeur de la surface spécifique des particules de la fraction inférieure à 2 μ et la qualité de celle-ci. L'équation Freundlich-Kuron exprime elle aussi la même chose :

$$a = \alpha\left(\frac{p}{p_0}\right)^{\frac{1}{n}},$$

a — la quantité de l'eau adsorbée par 1 g de sol,
p_0 — la pression des vapeurs d'eau saturées,
p — la pression des vapeurs d'eau dans les conditions opératoires,
α — la constante liée surtout à la surface des particules,
$\frac{1}{n}$ — la constante caractéristique de l'adsorbant.

Les résultats cités correspondent à ceux de la littérature (Demolon, 1960 ; Johansen et Dunning, 1960 ; Juhász, ils indiquent pour la plupart des cas une concordance linéaire entre la valeur „hy" et les autres propriétés.

Tableau 1

Le coefficient d'hygroscopicité „hy" de la fraction inférieure à 2/μ, isolée de différents minéraux et sols, saturée en ions d'hydrogène

Dénomination du matériel étudié	Coefficient d'hygroscopicité („hy")
Carbonate de calcium*	0,30
Dolomite	0,93
Orthose	0,85
Biotite	1,23
Kaolinite	1,51
Illite	2,84
Limonite*	2,87
Halloyisite*	4,87
Bentonite (Baia Mare)	7,65
Bentonite (Banat)	12,91
Sol podzolique à horizon argiloilluvial, horizon A_2	4,27
Sol brun forestier, horizon *A*	5,19
Chernozem dégradé, horizon *A*	5,04
Solonchak, horizon *AGS*	7,01
Solonoir de prairie humide (à nappe permanente) horizon *A*	8,26

* Non saturé en ions d'hydrogène.

Tableau 2

Constantes de l'équation Freundlich-Kuron pour quelques mineraux argileux

Dénomination du matériel	$\frac{1}{n}$	α
Orthose	0,286	0,58
Kaolinite	0,666	1,66
Illite	0,709	3,31

Tableau 3

Le coefficient „hy" et quelques propriétés physiques et phisico-chimiques de la fraction < 2/μ

Matériel étudié	„hy"	Valeur *T* (m.e.) pour 100 g de matériel	Stabilité mécanique de la structure (2,5 — 3,0 mm ⌀) (kg/agrégat)	Plasticité		Eau morte %
				limite inférieure	limite supérieure	
Orthose	0,85	13,4	0,11	43,77	43,77	5,15
Kaolinite	1,51	12,6	0,41	46,40	74,59	26,96
Illite	2,84	24,5	2,10	52,83	150,00	28,27
Bentonite	7,65	78,3	4,44	65,40	643,20	31,13

Tableau 4

Le coefficient „hy" la composition granulométrique et quelques proprietés physiques et physico-chimiques de certains sols étudiés

Type de sol	Fraction granulométrique (g/100 g sol sans humus et $CaCO_3$) 0,002 mm ⌀	0,002—0,02 mm ⌀	0,02—0,02 mm ⌀	0,2—2 mm ⌀	„hy"	Valeur T m.e. pour 100 g de sol	Stabilité mécanique des agrégats de 2,5—3 mm ⌀ (kg/agrégat)	Plasticité (%) limite inférieure	limite supérieure	Eau morte (%)
Sol podzolique à horizon argilo-illuvial; horizon A_2	18,40	45,93	31,87	3,80	1,40	10,50	0,58	27,86	32,56	6,12
Chernozem dégradé; horizon A	46,87	33,91	18,47	0,75	3,90	26,36	1,97	35,10	43,82	13,50
Sol noir de prairie humide (à nappe permanente) horizon A	50,34	29,24	18,63	1,79	5,68	47,80	3,77	42,48	55,75	19,33

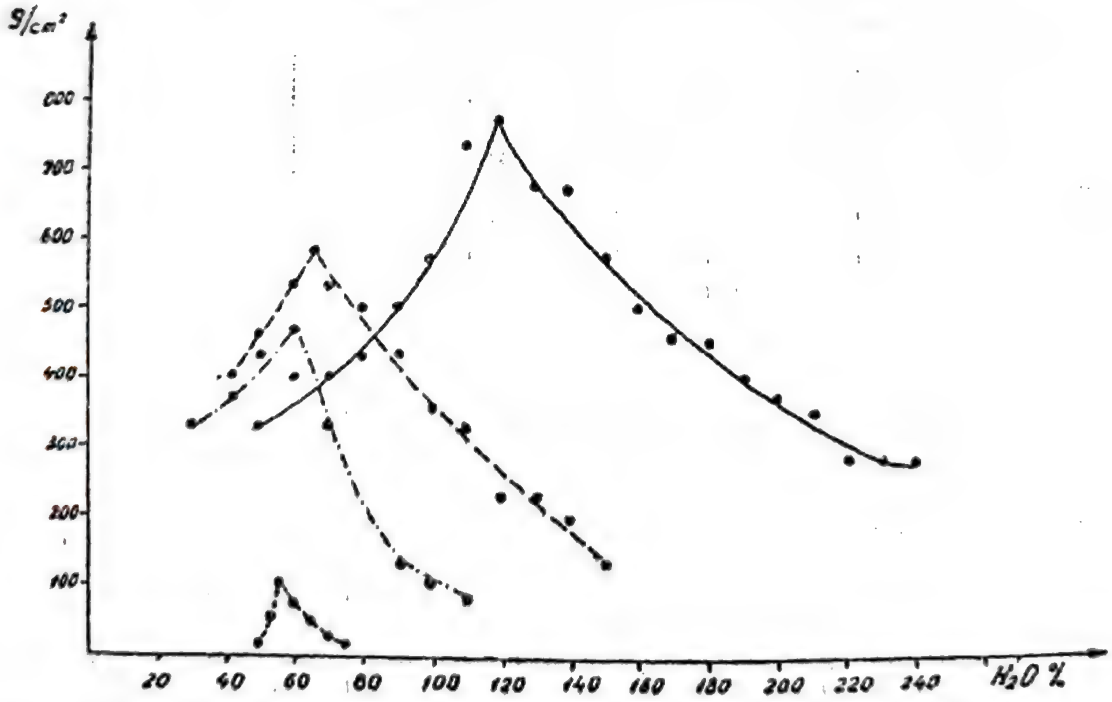

Fig. 1. Graphique de l'adhérence pour quelques minéraux argileux (fraction < 2 μ): ------orthose; -·-·-·- kaolinite; — — — — illite; ———— bentonite.

De même, ces résultats confirment l'importance du coefficient de Kuron pour l'expression unitaire, résultant des effets de la composition granulométrique et de la nature minéralogique de la fraction $< 2\mu$, pour les propriétés

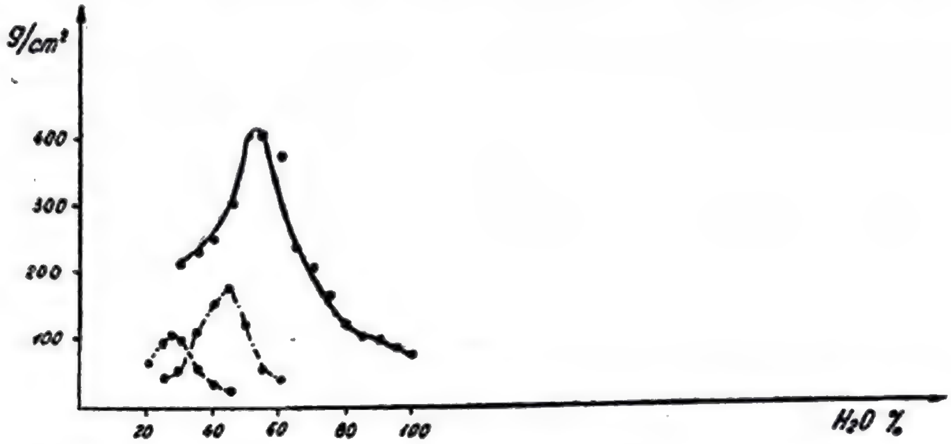

Fig. 2. Graphique de l'adhérence pour quelques échantillons de sol: - - - - - - - sol podzolique à horizon argilo-illuvial (horizon A_2) -·-·-·-·- Chernozem dégradé (horizon A); ——— Sol noir de prairie humide à nappe permanente (horizon A).

physiques et physico-chimiques des sols. L'importance de cette valeur indicatrice du coefficient de Kuron justifie notre recommandation d'utiliser ce coefficient comme complément de l'analyse mecanique.

D'autre part, l'analyse mécanique d'environ 500 échantillons de sols, leur identification texturale par palpation et la détermination du coefficient de Kuron nous ont permis d'établir la correspondance présentée dans le tableau 5, entre les espèces de sols et les valeurs du coefficient de Kuron (les sols intensément humifères étant exceptés). Cette correspondance nous a permis de recommander l'utilisation du coefficient de Kuron comme remplaçant de l'analyse mécanique, pour l'identification rapide de la texture des sols et pour leur classification texturale dans la cartographie des sols pour des buts agronomiques.

Tableau 5

La correspondance entre les classes texturales et les valeurs du coefficient de Kuron

Classe texturale	„hy"
sableux	$<0,49$
sablo-limoneux	0,50—1,49
limono-sableux	1,50—2,49
limoneux	2,50—3,74
limono-argileux	3,75—4,99
argileux	$>4,99$

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RÉSUMÉ

Les auteurs apportent de nouvelles contributions à l'utilisation du coefficient de hygro scopicité d'après Kuron, en vue de la détermination de la texture du sol.

On a utilisé dans les recherches effectuées la fraction au-dessous de 2 μ, saturée d'ions d'hydrogène isolée de différentes roches, minéraux et sols.

Se basant sur les résultats obtenus, on a constaté que les propriétés physiques, chimiques et biologiques de la fraction au dessous de 2 μ varient suivant la qualité de celle-ci. La valeur „hy" reflète précisément les différences qualitatives.

Les auteurs proposent, pour exprimer la texture du sol, l'emploi sur une large échelle de la valeur „hy", tant pour des buts pratiques que dans certaines recherches scientifiques.

SUMMARY

The authors bring new contributions to the use of Kuron's hygroscopic coefficient for the determination of soil texture.

Investigations have been carried out in which the fraction below 2 μ, saturated with hydrogen ions, isolated from different rocks, minerals, and soils was used.

On the basis of the results obtained, it has been established that the physical, chemical and biological properties of the fraction below 2 μ vary according to its quality. The ,,hy" values reflect precisely these qualitative differences.

For soil texture determination, the authors suggest the use of the ,,hy" value on a large scale, for practical purposes as well as for certain scientific research.

ZUSAMMENFASSUNG

Die Mitteilung bringt neue Beiträge zur Anwendung des Hygroskopizitätskoeffizienten nach Kuron „hy" bei der Bestimmung der Bodentextur.

Bei den unternommenen Untersuchungen wurde die mit Wasserstoffionen gesättigte Fraktion unter 2 μ verwendet, die aus verschiedenen Gesteinen, Mineralien und Böden abgesondert wurde.

Auf Grund der erzielten Ergebnisse wurde festgestellt, dass die physikalischen, chemischen und biologischen Eigenschaften der Fraktion unter 2 μ in Abhängigkeit von der Qualität derselben voneinander abweichen. Der „hy"-Wert widerspiegelt eben die quantitativen Unterschiede.

Die Verfasser schlagen vor, den „hy"-Wert weitgehend sowohl für praktische Zwecke als auch in gewissen wissenschaftlichen Forschungen zu verwenden, um die Bodentextur auszudrücken.

DISCUSSION

M. DE BOODT (Belgique). Pourriez-vous donner de plus amples explications sur la méthode employée pour déterminer le coefficient d'hyrgroscopicité de Kuron?

M. NEMEŞ. Une quantité déterminée de sol (10g) séché à l'air est placée dans un exsiccateur, où se trouvent 100 cm^3 de SO_4H_2 50%.

On l'y maintient pendant 72 heures, après quoi on en détermine l'humidité.

C. D. CHIRIŢĂ (République Populaire Roumaine). Quelle est l'influence de la matière organique du sol sur la valeur du coefficient de Kuron? Les limites établies par vous sont-elles valables aussi pour des sols riches en matière organique?

M. NEMEŞ. La teneur en matière organique jusqu'à 6—7% n'exerce pas d'influence sensible sur le coefficient d'hygroscopicité. Pour les sols à teneur plus élevée en matière organique, il est nécessaire d'élaborer une autre échelle.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I. 36

AUXILIARY MODERATORS TO IMPROVE THE SENSIVITY AND RESOLVING POWER OF THE NEUTRON SCATTERING MOISTURE METER[1]

M. DE BOODT[2]

The use of material with a high hydrogen content as an auxiliary moderator, surrounding the source in order to improve the sensitivity and resolving power of the neutron scattering moisture meter was not favourably considered at its early stage of development. The reason is that the hydrogen in the moderating material will also slow down the fast neutrons and hence this process could produce a confounding effect on the slowing down of the neutrons due to the hydrogen of the soil water which has to be measured.

I. MATERIAL WITH A HIGH HYDROGEN CONTENT AS AN AUXILIARY MODERATOR SURROUNDING THE SOURCE

A first suggestion for using material with a high hydrogen content surrounding the source in the neutron scattering method was made at the same time but independently in two papers respectively by Kühn (1959) and by Mortier, De Boodt and De Leenheer (1959). Both papers suggested to use paraffin surrounding the fast neutron source to get better results. Although at a first glance one might think that by using an auxiliary moderator, such as paraffin, the sensitivity of the method would be reduced, the above cited authors show that an improvement in sensitivity is obtained (see fig. 1).

In this figure calibration curves are given for the moisture determination of two different apparatuses both with and without a paraffin coat around the neutron source. The gain in sensitivity is obvious.

Although the data from Mortier, De Boodt, De Leenheer (1959) cannot be compared directly with the data of Kühn (1959) as two completely different apparatuses were used, the following conclusions may be drawn:

1) surrounding the neutron source with paraffin results for each apparatus in a steeper inclination of the calibration curve and hence in an improved sensitivity.

[1] Research subsidized by the „Fonds National de la Recherche Scientifique". Brussels.
[2] The State Agricultural University, Ghent, BELGIUM.

2) the increase in sensitivity is smaller when the wall of the paraffin ring around the source is 10 mm than with a 3 mm wall-thickness.

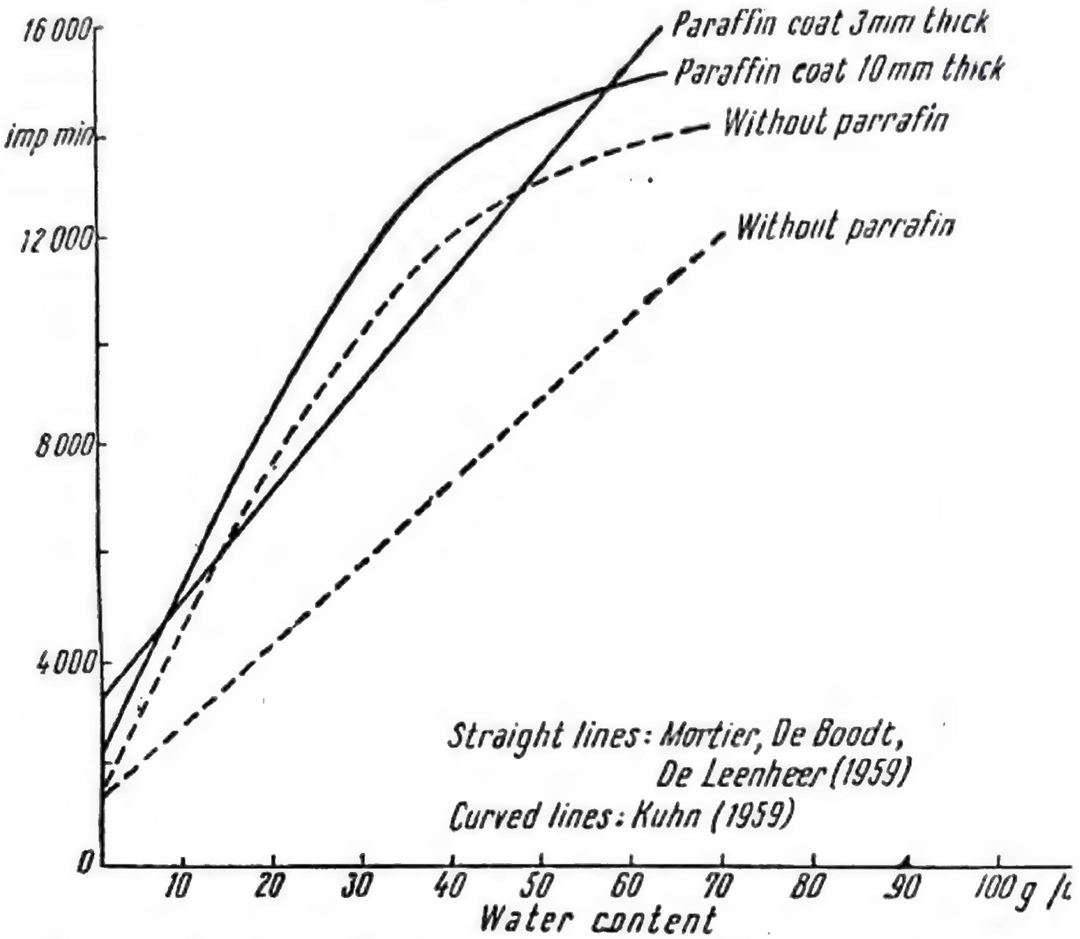

Fig. 1. Calibration curves for moisture determination from two different apparatuses, each time with and without a paraffin coat around the neutron source.

a. *Increasing the sensitivity*

As paraffin is temperature sensitive, it might be possible that it would not keep its geometric shape in all circumstances. As pointed out by De Boodt et al. (1963), to get reproducible results the precise geometrical position of all parts in the immediate vicinity of the source is of the utmost importance. Therefore it is recommended to use rigid material with a high hydrogen content.

In table 1 the materials are listed which at a first glance can be used for such purposes. Thus, for instance neopreen and most polyvinyl resins were not suitable because of the presence of chlorine ions, which also capture slow neutrons.

In the first experiment of a series which will be reported here three different materials were used to surround the source: one with zero per cent hydrogen besides a resin with a high (14.3 per cent) and one with a low (8 per cent) hydrogen content; they were respectively: aluminium, polyethylene, plexiglas (lucite).

The equipment consisted of a probe (source-counter assembly) 32 mm in diameter with halfway on the micro BF_3 counter (active lenght 25.4 mm) four 5 mC Ra-Be sources mounted symmetrically around it (see fig.2). During

Table 1

Formula and hydrogen content of materials which can be used as auxiliary moderator surrounding the source

Name	Formule	Hydrogen content in weight percentage
Paraffin	$CH_3—(CH_2)_n—CH_3$;n=±30	14.3
Plexiglas (lucite)	$—[CH_2—C(CH_3)(COOCH_3)]—CH_2$	8
Polyethylene	$x—(CH_2—CH_2)_n —x$;n = = ± 10.000	14.3
Polystyrene	$[C_6H_5 — (CH—CH_2)]_n$	8.3

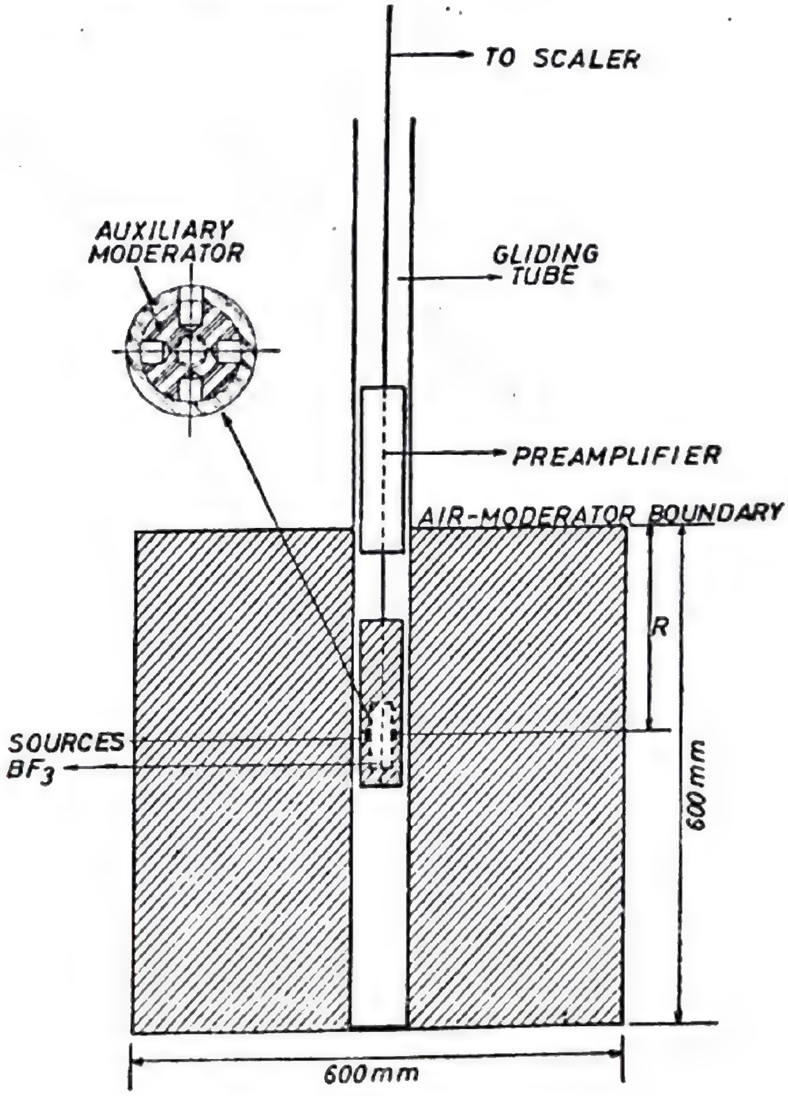

Fig. 2. Container with moderator, tube and source-counter-assembly.

three consecutive trials the four sources were surrounded by a 4-mm-wall ring (see fig.2), made respectively of aluminium, polyethylene and plexiglas. Each time a wetted front experiment was carried out by lowering the probe in the tube and registing the activity of the counter in accordance with of the distance from the air-moderator boundary. It was also possible to estimate the sensitivity and the resolving power of each of the three combinations.

Indeed, by means of a wetted-front experiment (Stone, Kirkham and Read, 1955) those two important characteristics of a given source-counter assembly can be studied in the following way:

1) by measuring in different media of well-known moisture content the distance R (see fig.2) at which the activity of the counter reaches its maximum, one knows at the same time the radius of the sphere of influence (van Bavel et al. 1954—1956) and hence the resolving power;

2) by plotting the maximum activity of the counter as function of the moisture content of the media; one estimates the inclination of the calibration curve and hence the sensitivity.

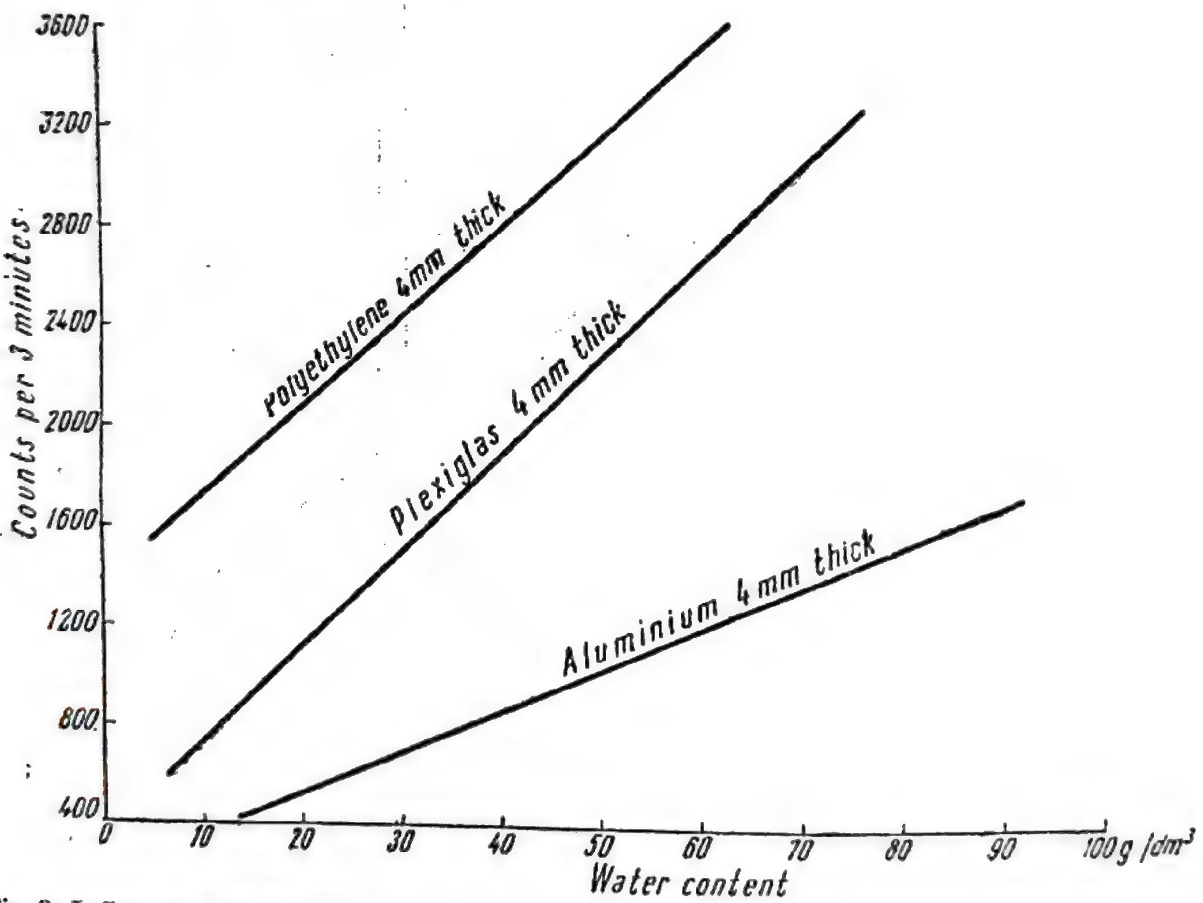

Fig. 3. Influence of the hydrogen content of the material surrounding the neutron source, on the inclination of the calibration curve.

By using six different moisture contents of the moderator, the calibration curve of each mentioned probe-combination was established (see fig.3).

The following conclusions may be drawn:

1. The inclination of the calibration curve is improved when a ring made of material with a high hydrogen content is put around the sources as compared with the case when an aluminium ring is put around them.

2. An even higher sensitivity is reached when the 4 mm thick auxiliary moderator contains 8 per cent instead of 14.3 per cent hydrogen.

In the second experiment of the series reported here the four 5 mC Ra-Be sources were replaced by one 20 mC Ra-Be source underneath the BF_3 counter but surrounded a first tim by a 10 mm-wall polyethylene ring and a second time with a 10 mm-wall aluminium ring. The two calibration curves thus obtained showed practically no mutual difference but they were poorer than the three calibration curves obtained in the first experiment.

b. *Improving the resolving power*

The wetted-front experiment also makes it possible to estimate the resolving power by evaluating the sphere of influence in media with different moisture content by measuring the R values.

The results obtained in the first experiment are given in table 2.

Table 2

Radii of the sphere of influence when a 4 mm-thick coat with different hydrogen content is surrounding the source, the moisture content of the moderator being X per cent by volume

X = (moisture content by volume percentage)	15.60	53.61	100
aluminium 0 per cent	20 cm	13 cm	10 cm
polyethylene 14,3 per-cent H	16 cm	14 cm	10 cm
plexyglas 8 per centH	14 cm	10 cm	8 cm

The density of the media with 15.60, 53.61 and 100 per cent moisture respectively was 1.43, 1.42 and 1.00.

From these data it is obvious that plexiglas is by far the best auxiliary moderator to be put in the immediate vicinity of the source.

In the second experiment the radii of the sphere of influence show a smaller resolving power in the dry media ($X = 15.6$ per cent) when a 10 mm thick polyethylene coat is used ($R = 26$ cm) as against a 10 mm aluminium ring ($R = 22$ cm).

II. MATERIAL WITH A HIGH HYDROGEN CONTENT FOR MAKING THE PROBE ACCESS TUBES

Encouraged by the results obtained when using plastics with low total hydrogen content as an auxiliary moderator in the immediate vicinity of the source, we also studied the problem which material the access tubes would best be made of.

The classic way of measuring the soil moisture content with the neutron source consists in gliding the probe in a stainless steel or aluminium tube which is put into the soil.

Stainless steel tubes are very expensive and are difficult to shape and to close at the bottom. Aluminium tubes need a special outfit (high temperature) to get them soldered up at the bottom.

Plastic tubes are cheap and easy to shape. Moreover, they can easily be obtained even in developing countries.

In general the polyethylene type of tube (30 per cent filling stuff is usually added to it to obtain the right rigidity) is the most economical one. The hydrogen content is then by weight $14.3 \times 70 : 100 = 10.1$ per cent.

The 50 mm diameter tubes may currently be obtained with a wall-thickness of 4 or 6 mm. The question is whether these tube types are recommendable to increase the sensitivity and resolving power of the measurement.

The following experiment (the third one) was carried out to study the influence of hydrogen content of the access tubes.

The set of tubes tested consisted of two aluminium and two polyethylene tubes with different wall thicknesses.

The following combination of aluminium tubes was used:

tube A 1: inner diameter 48 mm; wall-thickness 1.5 mm; outer diameter 51 mm.

tube A 2: inner diameter 51 mm; wall-thickness 2 mm; outer diameter 55 mm.

tube A 3: tube A 1 being put in tube A 2: inner diameter 48 mm; wall-thickness 3.5 mm; outer diameter 55 mm.

The following polyethylene tubes were compared:

tube P1: inner diameter 51 mm; wall-thickness 4.0 mm.

tube P2: inner diameter 51 mm; wall-thickness 6 mm.

a. *Increasing sensitivity*

Two different apparatusses were used in the third experiment to check the influence of the hydrogen content of the access tube. Apparatus I, constructed at the Ghent University contained one 20 mC Ra-Be source and a 15 cm long BF_3 counter and had a 48 mm probe diameter; apparatus II was made by Berthold W. Germany and contained one 100 mC Am-Be source and a scintillation counter with a 50 mm diameter.

To show the influence of the diameter of the aluminium tubes when using Apparatus I, we refer to figure 4. It is remarkable that the calibration curves of tube *A2* and tube *A3* coincide. This means that the wall-thickness of the aluminium has no influence providing that the outer diameter is the same. The calibration curve with tube *A1* is however different. This means that the distance from the moderating substance (moist soil) to the source is very important.

The difference in inclination between tube *A1* and tube *A3* is to be explained by the fact that in tube *A1* the moderating substance is 2 mm closer

to the source than in tube $A3$. This shows the great importance of the geometrical position of the different parts in the probe.

When the influence of $A2$ aluminium tube is tested out as against the polyethylene tube $P1$ and $P2$ with apparatus II, having a paraffin ring around

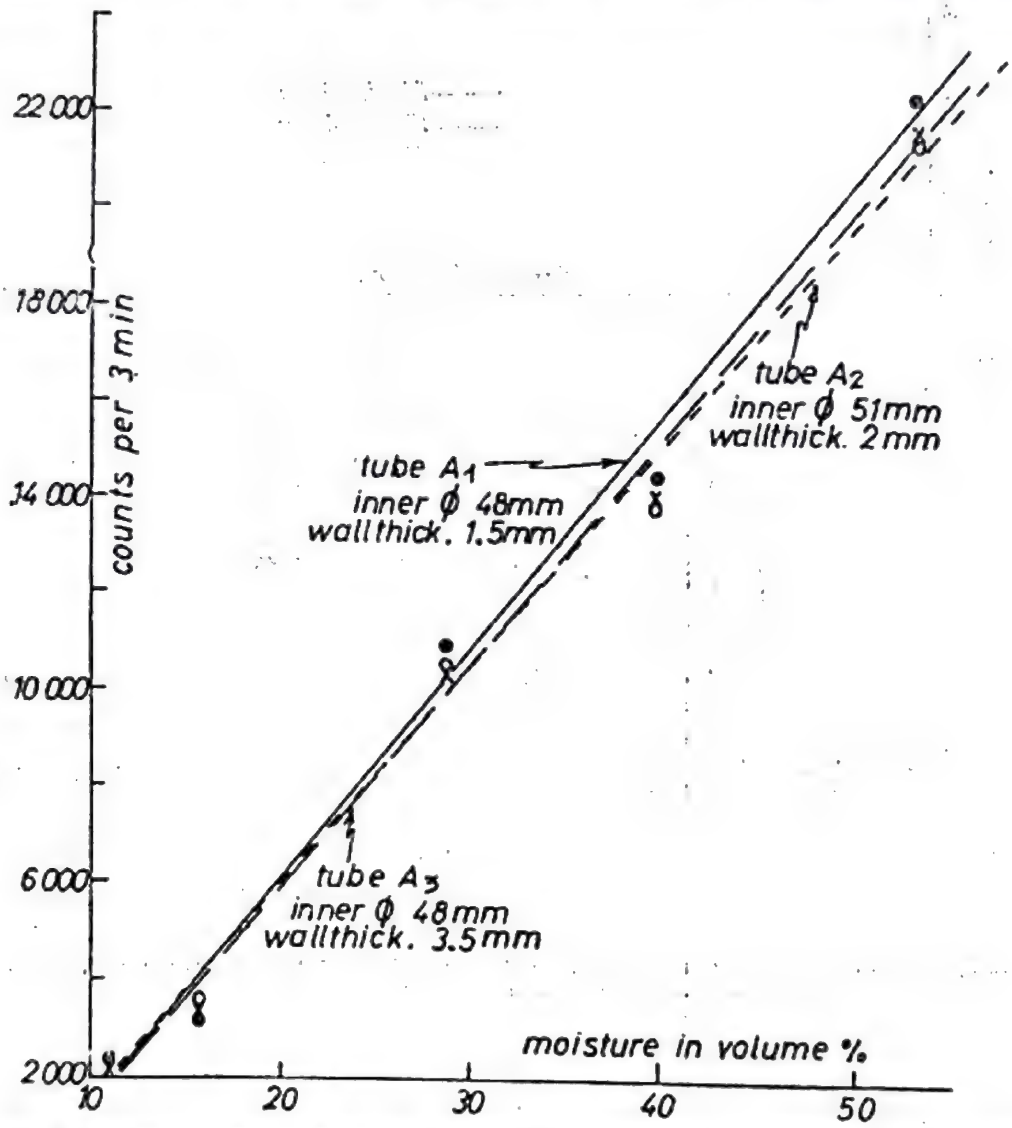

Fig. 4. Calibration curves when using aluminium access tubes of different wall-thicknesses and inner diameter.

the 100 mC Americium source, no appreciable gain in inclination is obtained, although from figure 5 it is clear that the improvement is maximum at a moisture content of 28.6 and 35.59 per cent.

b. *Improving the resolving power*

When wetted-front experiments are carried out to study the sphere of influence radii with apparatus I and II using diferent access tubes, table 3 is obtained.

The density of the media with respectively 11.46—15.60—28.46—39.58—53.75 and 100 per cent is of 1.1—1.42—1.45—1.43—1.18—1 respectively.

It is obvious that the access tube made of plastic material provides each time an appreciable smaller sphere of influence (compare the R values).

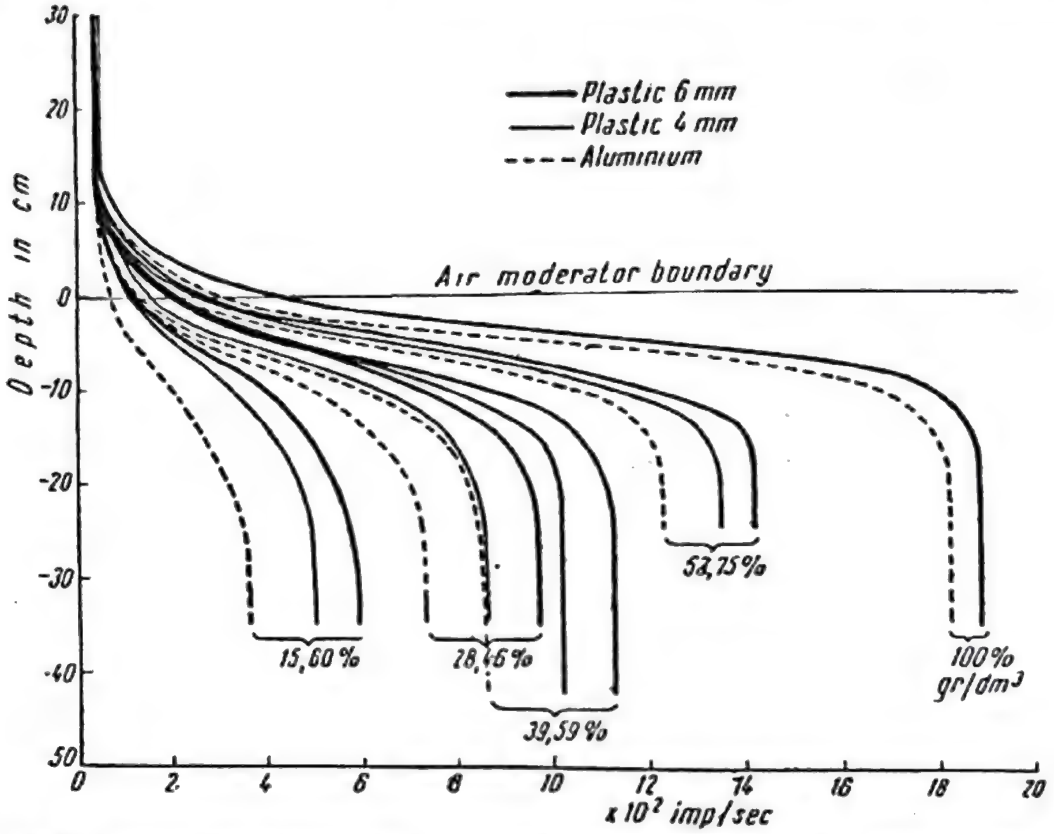

Fig. 5. Wetted-front experiment comparing an aluminium access tube with two plastic tubes of different wall thicknesses.

Table 3

Sphere of influence radii when two different apparatuses with different access tubes are used, X being the moisture content of the media in which the R values are measured

	X=(per cent)	11.46	15.60	28.46	39.58	53.75	100
Apparatus I	Plastic tube 4 mm	25 cm	22 cm	20 cm	15 cm	14 cm	12 cm
	Aluminium tube 2 mm	25 cm	25 cm	25 cm	20 cm	18 cm	14 cm
Apparatus II	Plastic tube 6 mm	—	25 cm	22,5 cm	20 cm	15.5 cm	14 cm
	Plastic tube 4 mm	—	25 cm	25 cm	20 cm	17.5 cm	14 cm
	Aluminium tube 2 mm	—	25 cm	25 cm	25 cm	22.5 cm	22.5 cm

III. EXPLANATION AND CONCLUSIONS CONCERNING THE OBSERVED PHENOMENA

Since thermal neutron density in the immediate neighbourhood of the source is increased by the presence of plastic material, fast neutron density in the remote region of the surrounding moderator (i. e. the soil) must be decreased. This means that the contribution of fast neutrons diminishes as the distance to the auxiliary moderator increases, which results in an improvement of the resolving power of the apparatus. Precision is also increased because all fast neutrons emitted by the source are scanning a smaller volume of the moderator when an auxiliary moderator is used in the immediate vicinity of the source. In such a set-up the auxiliary moderator is indeed acting as a virtual source of epithermal neutrons. This favourable influence is only observed when the hydrogen content of the auxiliary moderator lies between well drained limits.

Indeed, when the auxiliary moderator is very thick, a constant activity of the probe is registered irrespective the moisture content of the surrounding medium. If the hydrogen content of the auxiliary moderator is too low, not enough epithermal neutrons are formed. Therefore it is evident that there must be somewhere an optimum, which is in the neighbourhood of a 3 or 4 mm thick coat when using plastic material containing 8 per cent hydrogen. A wall-thickness of 10 mm of plastic material containing 14.3 per cent hydrogen for the ring surrounding the source is definetely too large.

When the auxiliary moderator is put at a relatively large distance from the source (2.5 cm as in the case of the plastic access tubes) no appreciable gain in sensivity is observed but only an improvement in the resolving power. This shows that besides the explanation given above, one also has to take into account the exact location where the greatest intensity of thermalized neutrons occurs in respect of the detector.

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SUMMARY

Experiments show that by surrounding the neutron source with a material having a high hydrogen content an improved sensitivity results (see fig. 1 and 3) was obtained; the optimum thickness of the coat being 3 or 4 mm. At the same time an improvement of the resolving power varying from 20 to 30 per cent (see table 2) is obtained. When the access tube of the probe is made of polyethylene instead of aluminium no marked effect on the sensitivity is obtained but on the resolving power (see table 3).

RÉSUMÉ

Les expériences démontrent qu'en entourant la source par une matière riche en hydrogène il en résulte aucune augmentation de la sensibilité (voir fig. 1 et 3), l'épaisseur optime de la couche étant de 3 à 4 mm. En même temps le pouvoir séparateur est amélioré de 20 à 30% (voir tableau 2).

Quand le tube d'accès de la source est en polyethylène au lieu d'aluminium, on n'obtient pas un effet marqué quant à la sensibilité mais bien quant au pouvoir séparateur (voir tableau 3).

ZUSAMMENFASSUNG

Aus Experimenten geht hervor dass eine Verbesserung der Genauigkeit (Abb. 1 und 3) der Ergebnissen bekommen wird wenn die Neutronenquelle mit einem Mantel aus wasserstofreichem Material umgeben wird. Die optimale Dicke des umgebenden Mantels ist 3 bis 4 mm. Zu gleicher Zeit wird das Auflösungvermögen mit 20 bis 30% erhöht (siehe Tabelle 2).

Wenn das Rohr in welches die Neutronenquelle sinkt aus Polyethylen statt Aluminium gemacht ist, bekommt man eine nenneswerte Verbesserung der Genauigkeit des Auflösungvermögens (Tabelle 3).

DISCUSSION

D. KIRKHAM (U.S.A.). How does the use of the several moderators influence the time of a moisture determination?

M. DE BOODT. Using an auxiliary moderator increases the number of counts and hence the time of moisture determination certainly has not to be increased.

E. VETTERLEIN (Deutsche Demokratische Republik). 1. Welche Arten von Neutronenquellen haben Sie verwendet? Haben Sie einen Einfluss der Art der Neutronenquellen auf den Verlauf der Impulsrate-Bodenfeuchtigkeitseichkurven feststellen können?

2. Welche geometrische Anordnung haben Sie für das Zählrohr und für die Neutronenquelle innerhalb der Neutronensonde gewählt?

3. Welche Anordnung des Hilfsmoderators in Bezug auf die Neutronenquelle ist nach Ihrer Erfahrung am zweckmässigsten?

M. DE BOODT. 1. Different sources were used. So we used one source of 20 mC Ra-Be put under the BF_3 counter, or 4 sources of 5 mC put coaxial around the BF_3 counter yielded each time a differently shaped curve. In some experiments we have been using a 100 mC Am-Be source put above a scintillation counter.

2. To get a straight calibration curve we put the source just at the height of the most sensitive part of the BF_3 counter which is mostly just at the middle of it. By putting the source above or under the BF_3 counter, a convex or a concave curve is obtained.

3. The auxiliary moderator is put as closely as possible coaxially around the source.

S. A. TAYLOR (U.S.A.). Are you prepared to recommend 4 mm wall thickness plexiglass for the access tube? Does the inside diameter of the tube have any influence? If so, what inside diameter is best?

Have you had experience with rate meters? The 3 minutes counting time is a disadvantage if large numbers of full measurements are needed.

M. DE BOODT. I think that we have to recommend the use of a plexiglass or polyethylene access tubes, as they are not only the cheapest and the most convenient to handle, in comparison with stainless steel or aluminium tubes, but they also improve the measurements as explained in the paper.

The inside diameter of the tube should fit very well the probe so that the distance of the probe versus the moderator should be very well reproducible in order to use the calibration curve correctly.

Rate meters are not as accurate as exact count meters. For field methods rate meters are sufficiently accurate but for laboratory research exact count meters are preferred. In rate meters a certain subjective factor is to be avoided.

J. W. HOLMES (Australia). Concerning the size of the probe and the internal diameter of the access tube : our probes usually have an outside diameter of 4.4 cm. and fit into a 5.4 cm diameter access tube. It is not necessary to consider excentric placement of the probe when it is hanging freely in the bore-hole in the soil. The error is less than 0.5 per cent. But when the probe is placed in the water drum for normalizing, the maximum difference in excentric placing, using one source placed on the side of the BF_3 tube, is about 3 per cent in the counting rate. The geometry should be carefully reproduced when placing the probe in the tube in the water drum, for normalising.

D. KIRKHAM. You state that it is quite important to have the probe centered well in the access tube. This places practical limitations on the neutron method because access tubes get bent or dented and the probe would get stuck if an accurate fit of the probe in the tube is made. Have you data on just what errors in moisture content would be made by not having a well-centered probe?

M. DE BOODT. If we look at figure 4 of this paper, we shall see that by putting the probe 2 mm further from the soil two different calibration curves are obtained ; the error being $\pm$ 3 percent. For practical work a very close fit of the probe into the access or gliding tube should be avoided and a play of 2 mm should be allowed. For research purposes the probe should fit as close as possible the access tubes.

J. W. HOLMES. Confirming Dr. De Boodt's findings that it is desirable to use an access tube made of polyethylene, rather than any metal tubing, because the plastic tubing makes the slope of the calibration curve steeper than it is with a metal tube, I would add a comment about installation. Sometimes it is necessary to put the access hole down to a depth of 12 meters or more, to make sure that the whole depth of root zone under forest trees is properly sampled. This can be done without an elaborate drilling, by using short lengths of polythene tubing. The first lenght to be installed should have a metal leading edge, or shoe attached to it. The soil is augered through the tubing, which is pushed in following the auger. The following lenghths of tubing are added by butt-welding, using a hot flat plate.

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APPLICATION OF ISOTOPES IN SOIL PHYSICS INVESTIGATION

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For the investigation of soil water properties, porous structure and processes of moisture movement in soils the method of radioactive isotopes is used. Complex chelated compounds of Co^{60} find application as unsorbing tracers ; in organic soils (peats) and sands also Na_2SO_4 with S^{35}, sugar with C^{14} and NaJ with J^{131} may be used.

The study of the porous structure of soils is carried out by displacing water, filling the pores of a water-saturated sample, with a solution of a radioactive tracer (Volarovich, Minkov, Churaev, 1957; Volarovich, Churaev, 1960, 1962; Volarovich, 1960; Churaev, Iljin, 1961). As a result of observations on kinetics of this displacement by the way of radiometrical analysis of effluant samples, data are obtained for the calculation of the volume distribution of watercon ducting pores by equivalent dimensions. In contrast to the known water-expelling methods by air or immiscible liquids, the use of a tracer solution makes it possible to avoid the deformation of samples during the experiment, due to the influence of colloidal-chemical variations, as the concentration of the radioactive addition is very small. However the method cannot be applied for the analysis of high-dispersed soil systems, where the influence of tracer diffusion and osmotic phenomena becomes considerable. Measurements of the water quantities, displaced by the tracer solution, make it possible to determine the active porosity of the investigated samples, corresponding to the content of water-conducting pores. For the measurement of the specific surface of a number of soils chemosorbtion of tracer compounds is used (Logginov, Rebinder, Abrosenkova, 1959).

For the characterization of a porous structure the values of coefficients D_k of convective diffusion are used (*Vlijanie svoistv*, 1962), the latter determining the character of local fields of flow velocities in soil pores. They may be found from the same filtration experiments on displacing water by radioactive isotopes. For these conditions the solution of the equation of convective diffusion is obtained (Churaev, Gamajunov, 1961). The values

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of D_k for a number of soils are equal to 10^{-3} cm^2/sec., which by two orders exceeds the values of the coefficients of molecular diffusion for the radioactive tracer in water.

Methods are worked out for the determination of D_k by way of measurement of the depth of the traced water front in soil columns or by observations of the movement of a narrow layer of water, containing a radioactive tracer (Rachinsky, 1958, 1959).

A radioactive tracer method is used for the determination of the water mechanically retained by soils (W_c)-immobilized by the structureof gel-, and intracellular water (Volarovich, 1960; Volarovich, Churaev, 1960, 1962; Volarovich, Lishtvan, Churaev, 1962). As the latter by its properties doesnot differ from free water, its content couldnot be determined by known methods. For this purpose a tracer modification of the insoluble volume method is used, and the concentration of the tracer at equilibrium is measured just after its addition and after mixing the suspension. This limits artificially the diffusion of the tracer into the immobilized and intracellular water, and gives the possibility to measure its content. The entrance of free water at the formation of a geleous structure in humic colloids is illustrated in figure 1. The development of geleous structures is caused here by the addition of $CaCl_2$ solution into the dispersion medium. As is seen from figure 1, the content of W_c is passing

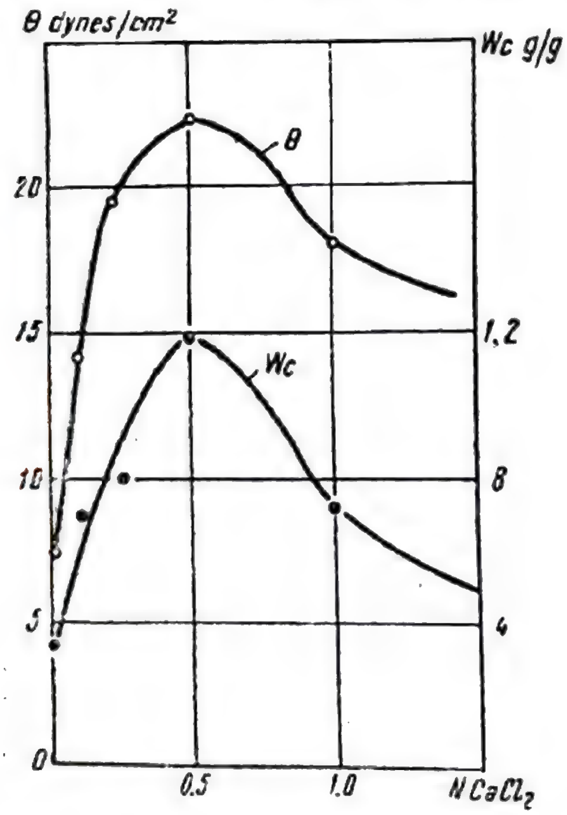

Fig. 1. The change of the immobilized water content W_c in humic colloids and of the strength θ, needed for the structure displacement of the gel, under the action of structure forming solutions.

here through a maximum, corresponding to the greatest development of geleous structures. That follows also from the observations of the change in the structure displacement strength θ. Further decrease in W_c and θ is cau-

sed by the development of a compact coagulation. On figure 2 the results of experiments are shown, where free traced water is entrapped, as the result of $CaCl_2$ action, by the structure of the forming gel. The destruction of this structure at the filtration of NaOH-solution through the sample leads to the disengagement of the entrapped traced water, which is testified by the appearance of activity in the filtrate.

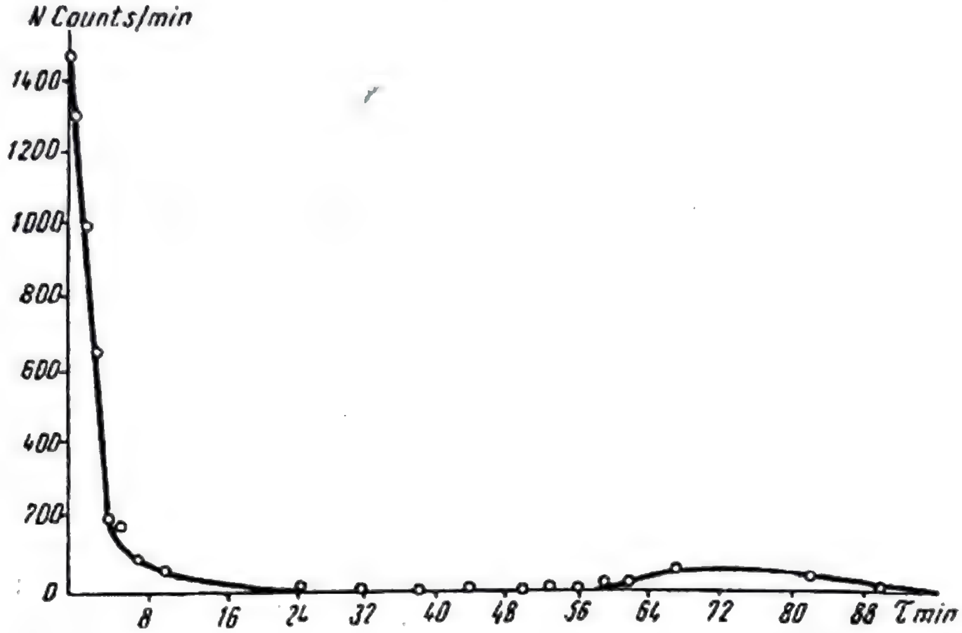

Fig. 2. The change in the radioactive tracer concentration in the effluent during filtration through the gel of humic colloids first of a $CaCl_2$-solution (τ = 0—50 min), then of a NaOH-solution (τ = 50—100 min). Measurements are made with the help of S^{35}-compounds, absorbed by the gel.

The soil investigation methods worked out are applied for the characteristics of soil water physical properties and analysis of structure formation, consolidation and dispersion (Volarovich, 1960; Volarovich, Churaev, 1962; Rachinsky, 1958, 1959; Volarovich, Lishtvan, Churaev, 1962; Lundin, 1962; Belikov, Emeljanov, Nesterov, 1961).

Radioisotopic methods find a wide application for investigations of soil moisture movement (Volarovich, Churaev, 1960; Rachinsky, 1958, 1959; Ludin, 1962; Belikov, Emeljanov, Nesterov, 1961; Churaev et al., 1960; Derjagin, Melnikova, 1957, 1950; Nerpin, Globus, Melnikova, 1962; Churaev, 1962, 1963; Djakov, 1961). Observations are performed on capillary rise of traced water in soil columns of different heights during evaporation from their surface Churaev, et al., 1960), and also at freezing (Djakov, 1961). As a result of the analysis of moisture content and specific activity of the samples, data were obtained which allow to conclude about the

considerable role of capillary-filtrational and film mechanisms in moisture conductivity. Techniques are worked out which give the possibility to distinguish between evaporation from the soil surface and from inside the pores (Churaev, 1962, 1963). During these experiments changes of the specific activity (S^{35}) of the drying sample surface are registered. The method is based on the conception that the radioactive tracer is transfered only by a liquid flow and concentrates on centres, where evaporation takes place. The results of experiments, carried out according to these methods, made it possible to find out the mechanism of moisture transfer in different soils during the process of drying and to observe the sequence of removal of different categories of bound water (Churaev et al., 1960; Churaev, 1962, 1963).

Moisture within soil samples can be transfered by vapour diffusion and as a liquid film (Churaev et al., 1963). Observations of the tracer concentration on the sample surface make it possible to calculate the quantity of moisture transfered as a liquid film and as vapour (Churaev, 1962, 1963). The increase in the relative humidity and the decrease of pore dimensions intensifies the transfer of film water.

The investigation of thermo-capillary movement of water under the action of a temperature gradient is carried out by means of the analysis of moisture distribution, specific activity and temperature along heat- and moisture isolated soil columns, preliminarly uniformly moistened with water, containing a radioactive tracer. The tracer distribution after establishment of a quasi-steady state allows to find out the influence of structure and moisture content of the samples upon the transfer mechanism of soil moisture under the action of a temperature gradient.

It is known, that the moisture quantity moving under the temperature gradient action in the direction of decreasing temperatures considerably exceeds the quantity, which can be transfered by the diffusion of water vapours. According to theory (Derjagin, Melnikova, 1957, 1950), the accumulation of moisture excess is caused by a liquid ("thermocapillary") flow, occurring as the result of a water surface tension gradient, arising in menisci of joint water under the influence of a temperature gradient. The phase composition of the thermo-flow was not ascertained by direct experiments and for its investigation radioactive tracers were applied (Nerpin, Globus, Melnikova, 1962). A most convenient tracer was found in Co^{60}, in the form of a salt of ethylene-dyaminetetraacetic acid.

With this tracer in closed horizontal columns the experiments were carried out with four soils of different mechanical composition at different uniformly distributed initial moisture content and with a stationary temperature gradient. After the end of the experiments the columns were unloaded by layers of 1 cm and in every layer moisture and specific radioactivity were determined.

The redistribution of water, accumulating at the "cold" end of the columns, markedly increases in all soils with the increase in the initial water content from the hygroscopicity to a maximum at a critical moisture

(W_{cr}), the absolute value of which is greater, the heavier the soil is. At a moisture content close to the field capacity, the thermocapillary flow goes out.

The redistribution of the tracer with increasing moisture on to W_{cr} also increases, but the accumulation takes place in the direction of the "hot" end, especially intensive transfer occurring at moistures greater than W_{cr},

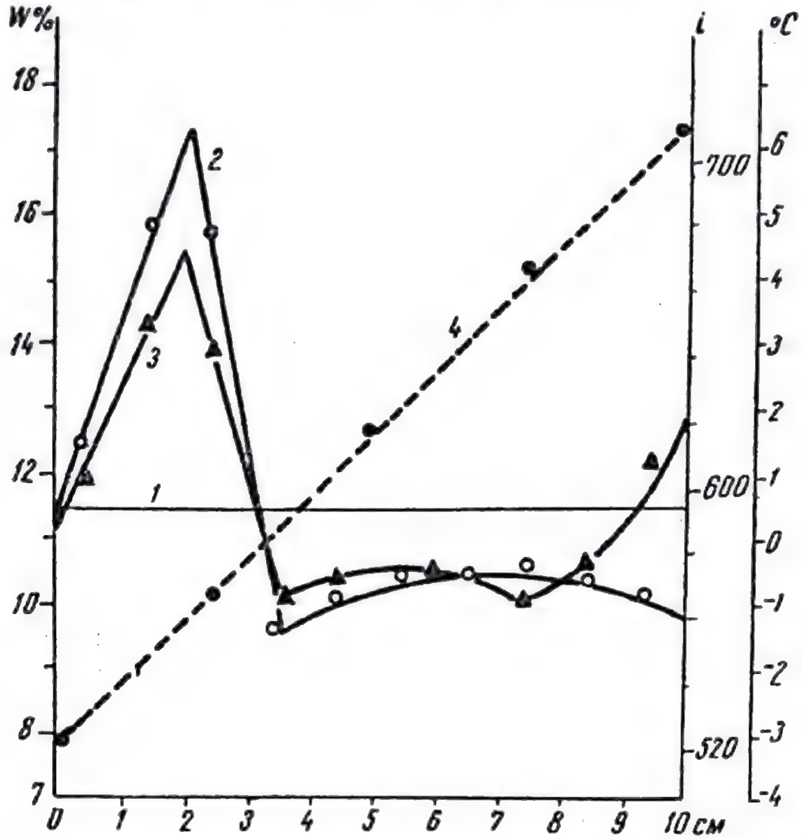

Fig. 3. The distribution of moisture W (per cent per weight) and radioactivity i (counts per min/g) in a heavy loam, as depending on the distance (cm) from the "cold" end of a soil column, under the influence of a temperature gradient. The initial soil moisture was 11.4% per cent:
1 — initial moisture and radioactivity distribution; *2* — final moisture distribution; *3* — final radioactivity distribution; *4* — temperature, °C.

and caused by a back flow of moisture under the influence of a moisture gradient, due to moisture accumulation at the "cold" end of the column.

Unfortunately, the absence of a specific tracer for the film water makes it impossible to differentiate between the film thermo-flow to the "cold" end and the ordinary capillary flow, moving in the direction of higher moisture potentials, i.e. to the "hot" end.

A different picture is observed when the "cold" end of the column is at negative temperatures: the water at this end freezes out and a back flow of moisture does not occur. In this case the tracer accumulates at the "cold" end and its distribution reproduces exactly the distribution of water (fig. 3). The main loss of moisture takes place from soil layers adjacent to

the "hot" end of the soil column. But a layer near the freezing zone is also drained out; such a depression zone is well known and is due to a quick decrease in moisture, which is not timely compensated by the flow from far-off layers.

The obtained results show the complexity of processes occurring at thermo-transfer of moisture in soils. At the increase in moisture in "cold" layers, saturation of small pores takes place, forming isolated water saturated zones; joint collars grow and the relationship between the joint and the film water changes: this leads to the decrease in the surface boundary "water-air" and lessens the thermocapillary effect; transit chanels appear, which unite the isolated water saturated zones. At the same time the "hot" layers of soil are depleted of water and there arises a gradient of moisture potential, directed from the "cold" to the "hot" layers, which does not exist in uniformly moistened soils.

A mixed mechanism of moisture transfer appears in the system: vapour diffusion within zones, occupied by the liquid phase; thermocapillary movement due to the gradient of water surface tension and directed to the "cold" end; filtration in water-saturated pores and film-flow from one meniscus to the other in an opposite direction.

In these complex conditions a tracer can remain in its initial position or move with a liquid flow in the direction of the "hot" end, that is observed in many experiments. In experiments with freezing soils the moisture potential decreases at the "cold" end and the tracer migration to the "hot" end is not observed. In these conditions the tracer accumulates near the "cold" end. It is also necessary to mark a systematic movement of the tracer at low moistures on the "hot" end, caused possibly by thermo-osmotic sliding of thin films (Derjagin, Melnikova, 1957, 1950).

For the investigation of the movement of water in soils in field conditions some methods are worked out, also based on the use of radioactive isotopes (Volarovich, Churaev, 1960; Belikov, Emeljanov, Nesterov, 1961; Volarovich, Minkov, Churaev, 1957, 1958; Astapov, Emeljanov, Shishkov, 1958; Iljin, Churaev, 1961; Flekser, 1961; Volarovich, Iljin, Churaev, 1961; Rozin, Evdokimova, 1960).

The first method, making it possible to determine the rate of underground flow, is based on observations of the change in the radioactive tracer concentration, introduced into a well drilled into the soil. The influence of the form and depth of the wells, of the frequency of water intermixing, of the regime of flow and of the tracer diffusion was established in laboratory experiments (Iljin, Churaev, 1961). It is shown, that if a number of easily to accoumplished conditions are maintained the method secures a high accuracy of measurements.

The second method, based on observation wells, is used for the determination of the direction and velocity of the ground water flow. The theory of this method was established (Volarovich, Churaev, 1960; Iljin, Churaev, 1961), making it possible to calculate from graphs of the variation of tracer concentration an average velocity of the water move-

ment in a section of the ground between the main well, into which a radioisotope was introduced, and the observation well, in which the tracer is captured. In the known formula for the observation wells method a correction is introduced, accounting for the exponential law of the tracer concentration changes in the main well. A combined application of the first and second methods allows to calculate the active porosity of the ground in the section under observation. Its values, as experiments show, can change in wide ranges, depending on macrostructure peculiarities. For the measurement of the tracer concentration in wells, a special radiometrical equipment may be applied (Flekser, 1961), as well as the method of testing ground water samples.

The third method is based on observations of the distribution of a radioactive tracer in soils by way of sampling and subsequent radiometrical analysis of samples, which are picked out in accordance with a coordinate net. When applying gamma-radiating isotopes (I^{131}), the measurements are carried out directly in the soil with the help of radioprobes. The probe represents a tube with a collimated detector for gamma-radiation, connected by a cable with a battery radiometer. The results of one such measurement, carried out in a peat-boggy soil, are shown on figure 4. The num-

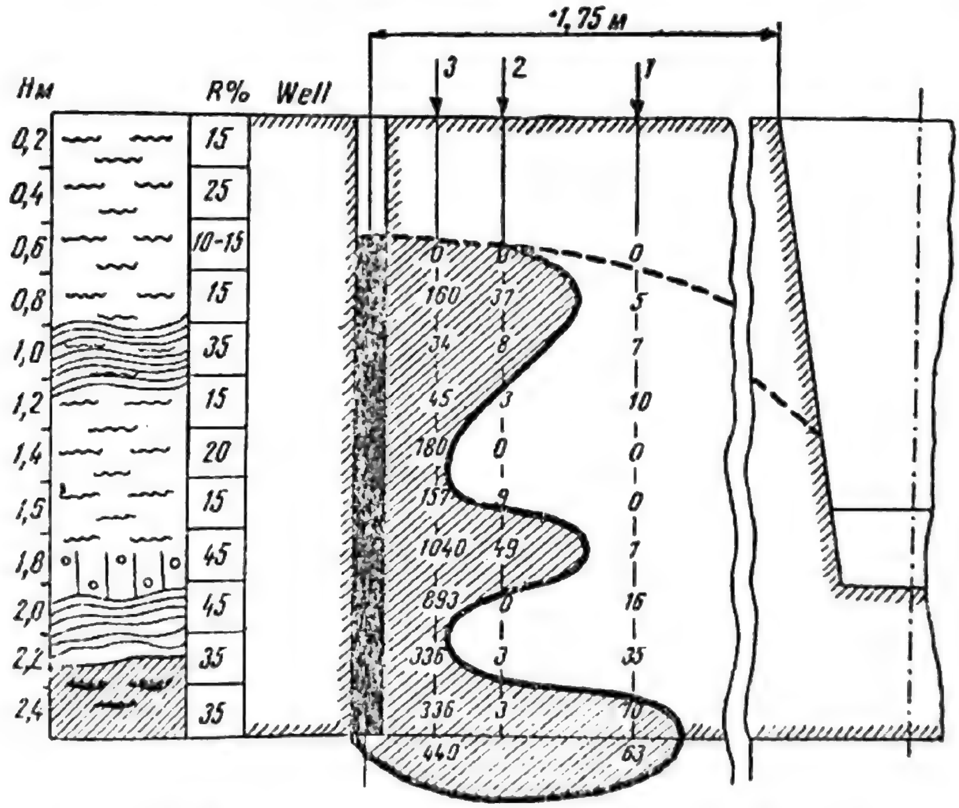

Fig. 4. The results of co-ordinate measurements of radioactivity by a radioprobe in a peat deposit at the depth H (m), 12 days after the introduction into a well of 15 cm of I^{131}. The figures indicate the specific radioactivity of the ground, registered by the probe at three distances (1, 2 and 3) from the well.

bers show the specific activity of samples, measured by the probe. As is seen from the chart, the movement of water in the direction of the draining ditch takes place within three water-conducting horizons; this is connected with the presence of a number of water-resisting interlayers with a high degree of decay (R).

These methods have been used for a great number of land-reclamation investigations (Volarovich, Churaev, 1960; Volarovich, 1960; Belikov, Emeljanov, Nesterov, 1961; Volarovich, Minkov, Churaev, 1957, 1958; Astapov, Emeljanov, Shishkov, 1958; Iljin, Churaev, 1961; Flekser, 1961; Volarovich, Iljin, Churaev, 1961; Rozin, Evdokimova, 1960), which allow to study the regularities of melioration of a number of soils and their structural peculiarities. The observations are also carried out on the movement of radioactive tracers in the upper layers of soil (Volarovich, Churaev, 1960, 1962; Volarovich, Iljin, Churaev, 1961; Rozin, Evdokimova, 1960), analogous to the methods of investigation with a salt tracer (Vasiljev, Rode, 1960). The existence was established of fluxes, differing in rate and direction, arising under the action of the gradient of water potential. A considerable role of the horizontal transfer of moisture is shown in the capillary fringe zone in the direction of open ditches.

The radioactive tracer method is used for the determination of hydraulic parameters of drainage works (Churaev, 1959). A radioactive tracer is introduced into a drain at a certain distance from the mouth. Determining from maximum activity in effluent samples of drain water, the passage time of a traced volume, one calculates the effective cross-section of the drains and the velocities of the water flow in them. This method is applied on a number of experimental plots for the comparison of different types of drain constructions and the establishment of the most effective ones.

Radioactive isotopes find an application for the determination of soil moisture and density in field conditions. As early as 1955 (Danilin, 1955) the perspective of gamma-rays for stationary observations of moisture changes in soils has been proved. This was the beginning of the working out of methods based on the use of gamma-rays, for field investigations of soils in the U.S.S.R. At present gamma-meters for observations of soil moisture changes (Danilin, 1958, 1961) are used successfully by a number of scientific research offices. The observation errors usually do not exceed 1—2 per cent.

A gammameter for the measurement of soil density (with an error of the order $\pm$ 0,02 g/cm^2) was also constructed with the help of a scintillation counter, with an amplitude integral discriminator of impulses. Working with such instruments, preliminary calibrating operations inevitable in the cases of gammascopical measurements of soil density by radiometrical instruments with gas-discharging gamma-counters, are not necessary.

Investigations on the neutron method for measurement of soil moisture have shown that variations of the granulometric composition of the soil do not influence the relationship between the velocity of the slow neutrons and the moisture, that is the basis of the method. Variations in the volume

weight of the solid phase of soil, its chemical, mineralogical composition and the chemical action of soil moisture have little effect on the neutron method in the absence of chlorine, boron and other strong anomalous absorbers of slow neutrons; their presence requires the introduction of corresponding corrections, the values of which are found out by simple methods. The errors of the neutron method do not exceed those of the oven-drying weighing methods. Some types of neutron moisture-meters were constructed, differing by a portability and simplicity of the construction of the radioelectronic blocks. Thus a surface depth neutron moisture-meter was made, securing with one and the same probe the control and calibration of the device as well as shallow and deep measurements. The radioelectronic blocks of the impulse registrator of this moisture-meter are connected on semiconductor triods and small tirotrones with a cold cathode.

A method for the measurement of the slow neutron flux is worked out by the captured gamma-radiation of cadmium, the intensity of which is proportional to the flux density. This makes it possible to use common gas-discharging gamma-counters (with a cadmium screen) in the probes of the neutron moisture-meters. This not only gives a considerable simplification and increased safety of the working with radioelectronic blocks, but also makes the measurements of moisture of salinized soils possible without the introduction of corrections for chlorine content. The distorting effect of chlorine manifests itself in the decrease of the density of the slow neutrons. But the chlorine nucleus at every act of the capture of such neutrons emits three capture-gamma-quantum. As gamma-counters react also upon the captured gamma-radiation of chlorine, the count velocity, corresponding to the value of a given moisture, is practically not affected by the presence of chlorine in the soil. The slope of the count velocity versus moisture relationship for moisture-meters with probes, having gamma-counters with cadmium screens, assures a good accuracy of the measurements in the range from 0 to 25—30 per cent of moisture in volume percentage.

A neutron moisture-meter with a small source of neutrons is offered, emitting neutrons only at a certain mutual position of the gamma-radiator and the beryllium target. Works are carried out on the construction of a radiometrical device with neutron source and gamma-radiator for one-positional measurement of the volumetric moisture of the soil and of the volumetric weight of the solid phase. It serves for the direct evaluation of weight moisture, and differs from the neutron moisture-meters combined with gamma-density-meters, which allow to obtain the moisture in per cent by weight only by calculation. Also new possibilities of the neutron method application in soil physics are revealed, for example for field investigations of water filtration, for the free water bonding and others.

The use of radioactive isotopes, as shown by the elaborated methods and the results obtained makes it possible to solve successfully different problems, connected with investigation on soil-water-properties, on the porous structure of soils and on soil moisture movement.

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SUMMARY

Different radioactive methods are proposed for the study of the porous structure and active porosity of soils, for the determination of coefficients of convective diffusion, for the investigation of the capillary rise of soil water, of water transfer by vapour diffusion and by film water, of the thermocapillary flow and others. In field conditions isotopes are used

for researches, related to the ground water flow, to drainage and reclamation works. Gamma-radiation and neutrons are used for the development of moisture- and density-meters for field measurements.

RÉSUMÉ

Différentes méthodes radioactives sont proposées pour la détermination de la structure des pores et de la porosité active dans le sol, des coefficients de la diffusion convective, de la distribution des vélocités et des directions du flux d'eau dans le sol. Des observations à l'aide des isotopes radioactifs sont faites sur l'ascension capillaire, sur le transport de l'eau par la diffusion de la vapeur et par les films d'eau, sur le flux thermocapillaire et autres. Dans des conditions naturelles, les isotopes trouvent leur application dans les recherches sur l'écoulement de la nappe phréatique et pour la solution de différents problèmes d'amélioration. Des appareils basés sur l'utilisation de la radiation gamma et des neutrons sont construits pour la détermination de la densité et du taux de l'humidité dans le sol.

ZUSAMMENFASSUNG

Es werden verschiedene radioaktive Methoden für die Feststellung der Porenstruktur und der aktiven Porosität, der Koeffizienten der konvektiven Diffusion und der Verteilung der Geschwindigkeiten und der Richtung des Wasserstromes im Boden beschrieben. Das Kapillaraufsteigen des Bodenwassers, die Übertragung des Wassers infolge der Dampfdiffusion und der Bewegung des Filmwassers, der thermokapillare Wasserstrom u.a. sind mit Hilfe der radioaktiven Isotope beobachtet worden. In Feldbedingungen dienen die Isotope der Beobachtung der Grundwasserbewegung, dem Vergleich verschiedener Meliorationsmassnahmen u.a. Methoden, auf der Verwendung von Gamma-Strahlen und Neutronen begründet, erlauben die Feuchtigkeit und die Dichte des Bodens im Felde zu bestimmen.

DISCUSSION

J. W. HOLMES (Australia). Could Mrs. Melnikova tell us a little more about the use of these radioactive techniques — I presume the neutron moisture meter — in chlorine containing soils?

M. K. MELNIKOVA. The details are published in a work by Mr. Emeljanoff and I could not say more than was already said by Mr. De Boodt.

S. A. TAYLOR (U.S.A.). Have you made a mathematical analysis to describe the flow of water and heat in response to a temperature gradient in the soil?

M. K. MELNIKOVA. Yes, we have. The analysis was published in the Symposium of Plant Nutrition held in India in 1962.

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THE DETERMINATION OF THE SOIL MOISTURE CHARACTERISTIC CURVE DOWN TO A MATRIC SUCTION OF ZERO INCLUSIVE

B. FOKKENS[1]

1. DESIGN

Soil moisture characteristic curves in the range of low matric suctions are obtained when undisturbed cores are sucked off on the well-known ceramic plates or on the "Sandbox-apparatus" described by Peerlkamp and Boekel (1960). In this procedure the water content of the cores is measured down to suctions of some centimeters water, depending on the height of the cores. The water content at matric suction $=0$ must be found by extrapolation.

In case very wide pores occur the water content found in this way might be too low as such wide pores will not be filled with water until the cores are fully saturated. Theoretically pores with a diameter greater than about 0.06 cm are only filled with water when suction is smaller than 5 cm (Marshall, 1959). According to Frei (1950) and Gracanin (1950) a diameter of 0.020 or 0.025 cm is the limit of visibility of soil pores. Thus when pores are seen clearly with the naked eye, cores with a height of 5 cm might not be saturated fully when the water-level is at the foot of the cores. Therefore a method is worked out to measure the water content at matric suction $=0$ directly. This comes to the weighing of fully saturated cores, the same cores that are used, in our case, on the sandbox-apparatus.

To test the new method, the water content at matric suction $=0$ measured in this way, is compared for a number of cores with the value found by extrapolation of the moisture characteristic curve. Also a comparison is made with the porosity, computed using the density and the apparent density. For the last named purpose it is necessary to measure the volume of the cores very exactly. And because most soils swell when they are saturated a method is also worked out to measure the swelling and to correct the original volume of the cores.

[1] Zuiderzeepolders Development Authority, Kampen, THE NETHERLANDS.

2. METHODS AND CALCULATIONS

To measure the water content at suction = 0 the cores in stainless steel cylinders (content 100 cm³, height 5 cm) are placed in a box with a layer of permeable material (coarse sand) on the bottom. The water-level in the box is raised gradually up to ca. 0.5 cm under the upper side of the cylinders. Thus, the air present in the cores has the opportunity to evade. The

Fig. 1*a*. Cylinder with lid on top, used for the weighing of fully saturated cores. Around the lid is the rubber ring in rolled-up position.

Fig. 1*b*. Cylinder with lid on top, used for the weighing of fully saturated cores. The rubber ring named in fig. 1*a* is rolled down.

time of saturation depends on the type of soil; this point is out of discussion here.

After the cores are saturated a lid with folded rim is placed on top of a cylinder (fig. 1*a*). The height of the lid is so that some room is left between the top-side of the cores and the lid. Around the lid is a rolled-up rubber ring (i.c. a part of an inner bicycle's tire); when this is rolled down the lid is fixed air- and watertight to the cylinder (fig. 1*b*).

Now the cylinder is drawn out the water with a fast movement, and turned over as soon as it emerges. The former lid acts from now on as the of the bottom, cylinder in which contingent water draining from the core is collected. It is proved by our experiments that, when operations are made accurately, the water that was in the core after it was saturated, keeps quantitatively in the cylinder with bottom. The apparatus is dried from the outside and placed on a balance to be weighed. After weighing the rubber ring is rolled down and the cylinder with the core is taken from the bottom. It can be used now on the sandbox-apparatus for the determination of the water content at higher suction values.

To measure the (linear) swelling of a core an apparatus as shown in figure 2 is placed on a cylinder. The apparatus has a ring that fits on top o

the cylinder. The smallest inside diameter of the ring equals the inside diameter of the cylinder. A horizontal plate is fixed at ca. 5 cm over the ring. Through holes in this plate five pins can be moved in vertical direction. The lower end of each pin, that is fitted with a small disc rests on the surface of the core insied the cylinder. On the pins there is a calibration that reads zero when the

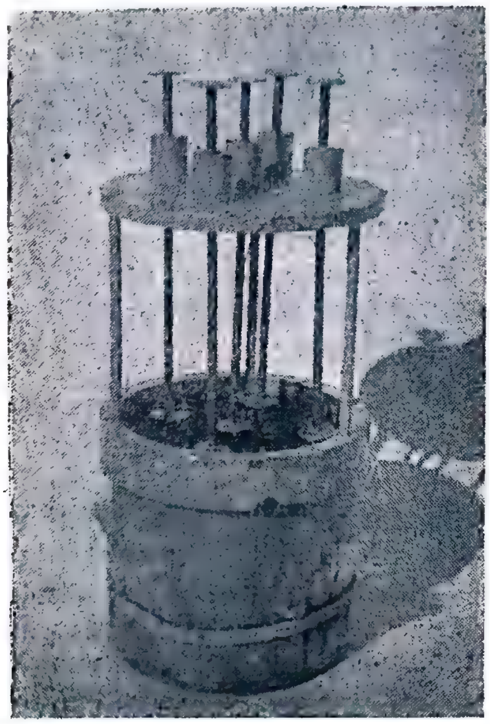

Fig. 2. Apparatus used for the measurement of the swelling of an undisturbed core in a cylinder.

lower end of the pins is in the plane through the upper end of the cylinder. When the surface of the core is higher than this plane, the swelling is calculated from the average reading of the calibrations on the pins. This is done by the following formula:

$$v_{sw} = \frac{100}{5} \times a \tag{1}$$

in which

v_{sw} — swelling (cm^3),
100 — content of a cylinder (cm^3),
5 — height of a cylinder (cm),
a — average reading of the pins (cm).

Since the original volume of the core is 100 cm^3, v_{sw} is also the percentage of swelling.

The water content at matric suction = O is calculated as follows:

$$w = \frac{g_{tot} - g_{app} - g_{soil}}{100 + v_{sw}} \cdot 1, \tag{2}$$

w = water content ($cm^3\ cm^{-3}$),
g_{tot} = weight of saturated core + cylinder + bottom + rubber ring (gm),
g_{app} = weight of cylinder + bottom + rubber ring (gm),
g_{soil} = weight of soil, dried at 105°C (gm),
1 = density of water ($cm^3\ gm^{-1}$).

The porosity is calculated by the formula

$$\varepsilon = \frac{(100 + v_{sw}) - g_{soil} \times \rho}{100 + v_{sw}}, \tag{4}$$

in which

ε = porosity ($cm^3\ cm^{-3}$),
ρ = density of soil ($cm^3\ gm^{-1}$).

The density of the soil is computed from the organic matter content, assuming the density of mineral soil particles = 0.376 $cm^3\ gm^{-1}$ and the density of organic matter = 0.680 $cm^3\ gm^{-1}$.

3. RESULTS

Experiments were made with 12 soils from the polder "Eastern Flevoland" in the Netherlands. This polder was drained from "the Yssellake" fresh-water lake 7 years before the samples were taken. At a depth greater than 50 to 100 cm below surface the soils are still unripened. This means that no air is present in the soil and that only small to very small primary pores occur (Fokkens and De Koning, 1960). In the top soil air has penetreted and, when clay content is higher than ca. 10%, permanent cracks are present. The upper 20 cm was ploughed for some years.

From 6 types of unripened soils a sample was taken, each sample consisting of 4 undisturbed cores. 3 samples were taken from cracked soil-layers and also 3 samples from ploughed layers, the last 6 samples each being composed of 5 indisturbed cores. The samples were taken early in spring. A survey of the samples is shown in table 1.

For each sample the following determinations are made: the porosity (ε), the water content at matric suction = 0 by extrapolation of the moisture characteristic curve made from matric suction of 100 cm up to 2.5 cm water (w_0') ant the water content at matric suction = 0 by the "lid-bottom method" (w_0).

To calculate ε at matric suction = 0 the swelling of the cores is measured by the "pins method". To test the last named method also a value for the porosity is calculated when no correction is made for the swelling (ε'), and also when the volume of the cores is supposed to be 100 cm^3 (formula 3: $v_{sw} = 0$).

In table 2 the difference between ε' and w_0' can be compared with the difference between ε and w_0'. The same comparison can be made for the difference between ε' and w_0 and ε and w_0.

It is evident from such comparisons that a distinction occurs between the samples 1 to 6 and the samples 7 to 12. Correcting the porosity of the

Table 1

Survey of the samples, used for testing the "lid — bottom method" to measure the water content at matric suction = 0 and the "pins-method" to measure the swelling of soil cores

No of sample	Type of soil	Clay (gm 100 gm^{-1})	Organic matter (gm 100 gm^{-1})	Water content (cm^3 cm^{-3}) field-fresh	Air content*) (cm^3 cm^{-3}) field-fresh	Soil structure
1	peat	—	92.8	0.894	+0.028	unripened: not aerated, no wide pores
2	peat detritus	ca. 20	45.9	0,896	—0.008	id.
3	clay loam	30.5	2,6	0.670	—0.002	id.
4	sandy loam	8.7	2.3	0.519	—0.001	id.
5	very fine sand	2.8	0.6	0.457	+0.013	id.
6	coarse sand	2.0	0.3	0.340	+0.019	id.
7	clay loam	31.8	3.1	0.469	+0.087	oxidized, cracks
8	loam	20.6	2.4	0.493	+0.077	id.
9	sandy loam	14.5	2.1	0.488	+0.045	id.
10	clay loam	28.5	2.7	0.445	+0.072	oxidized, ploughed
11	loam	25.6	3.2	0.411	+0.195	id.
12	sandy loam	16.7	2.8	0.430	+0.148	id.

*) Porosity (computed using density and apparent density) minus water content.

Table 2

The difference between the porosity and the water content at matric suction = 0, before and after the porosity is corrected for the swelling measured by the "pins method"; ε' = porosity without correction; ε = porosity with correction; w_0' = water content by extrapolation of the moisture curve; w_0 = water content by the "lid — bottom method". This values are given in cm^3 cm^{-3}. The samples are described in table 1.

No. of sample	% swelling	ε	$\varepsilon'—w_0'$	$\varepsilon — w'$	$\varepsilon' — w_0$	$\varepsilon — w_0$
			not corrected	corrected	not corrected	corrected
1	+5.0	0.903	—0.039	+0.006	—0.040	+0.005
2	+6.8	0.880	—0.069	—0.010	—0.070	—0.011
3	+1.5	0.677	—0.013	+0.002	—0.014	+0.001
4	+1.7	0.528	—0.015	—0.001	—0.015	—0.001
5	—0.4	0.488	+0.003	+0.001	+0.010	+0.006
6	—0.6	0.349	+0.013	+0.007	+0.013	+0.007
7	+1.2	0.562	+0.019	+0.031	+0.006	+0.020
8	+1.2	0.577	+0.023	+0.035	+0.012	+0.024
9	+0.8	0.538	+0.009	+0.018	—0.001	+0.008
10	+1.2	0.520	+0.027	+0.038	+0.021	+0.032
11	+1.0	0.615	+0.063	+0.074	+0.021	+0.032
12	+0.8	0.582	+0.066	+0.075	+0.034	+0.042
I	II	III	IV	V	VI	VII

first named samples for swelling considerably decreases the original difference between porosity and water content at matric suction $=0$, that is from up to -0.070 cm³cm⁻³, considerably to values not greater than- 0.011 cm³ cm⁻³. Since these samples do not contain air (see table 1), porosity and water content should then be the same. Hus the results of these samples seem to prove that the corrected value is exact and this means that the swelling of the cores is measured correctly by the "pins-method". In the case of samples 7 to 12 the difference between porosity and water content at matric suction $=0$ is not nullified or strongly reduced by correcting the value of the porosity; with these samples it became even greater. This distinction might be caused by entrapped air since the samples are aerated and, as to $\varepsilon - w_0'$, also by wide pores in the form of cracks or holes in the ploughed layer (table 1). That this theory holds is shown in table 3.

Table 3

The air content of fully saturated samples ($\varepsilon - w_0$) and the volume of wide pores, which is not measured if water content at matric suction = 0 is determined by extrapolation of the moisture characteristic curve ($w_0 - w_0'$). w_{100} = water content at matric suction = 100; ε = porosity; w_0 = water content by the "lid-bottom method"; w_0' = water content by extrapolation. This values are given in cm³ cm⁻³. The samples are described in table 1

No of sample	$w_0 - w_{100}$	$\varepsilon - w_0'$ (entrapped air)	$w_0 - w_0'$ (wide pores)	$\frac{\varepsilon - w_0}{w_0 - w_{100}} \times 100$	$\frac{w_0 - w_0'}{w_0' - w_{100}} \times 100$
1	+0.183	+0.005	+0.001	3 percent	1 percent
2	+0.051	—0.011	+0.001	—	2 percent
3	+0.020	+0.001	+0.001	5 percent	5 percent
4	+0.022	—0.001	0	—	0 percent
5	+0.032	+0.006	—0.005	19 percent	—
6	+0.197	+0.007	0	4 percent	0 percent
7	+0.070	+0.020	+0.011	29 percent	19 percent
8	+0.053	+0.024	+0.011	45 percent	27 percent
9	+0.037	+0.008	+0.010	22 percent	37 percent
10	+0.044	+0.032	+0.006	73 percent	18 percent
11	+0.130	+0.032	+0.042	25 percent	48 percent
12	+0.082	+0.042	+0.033	51 percent	67 percen
I	II	III	IV	V	VI

The content of entrapped air at matric suction $=0$ must equal the value $\varepsilon - w_0$. In case no air is present in the soil (samples 1 to 6) this value then is very low. When the soil is aerated (samples 7 to 12), much greater values for $\varepsilon - w_0$ are measured. And for the ploughed layer (samples 10—12), where air content can be expected the highest, $\varepsilon - w_0$ is greater than for the layer underneath (samples 7 to 9). The results obtained with the airless samples points out that $\varepsilon - w_0$ really is a quantitative measure for the air content. If this is true, the top soil (samples 7 to 12) can contain up to 0.042 cm³ cm⁻³ air when matric suction $=0$. This figure is rather high in proportion to the quantity of water that can be drained between matric

suction $= 0$ and matric suction $= 100$; mamely up to 73 percent. So one should be careful to interpret this quantity of water as the air content of a soil at field capacity.

When water content at matric suction $= 0$ is measured correctly by the "lid — bottom method" the value of $w_0 - w_0'$ is equal to the volume of the wide pores that are not measured by the extrapolation of moisture characteristic curve. According to table 3 this value then approximates zero when no wide pores occur, as in the samples 1 to 6. On the other hand, in the ploughed layers this value is up to 0.042 $cm^3\ cm^{-3}$ and in the layers underneath up to 0.011 $cm^3\ cm^{-3}$. Considered absolutely the last named value seems not very high. But in case moisture characteristic curves are used to calculate the drainable pore space of a soil profile, the value has to be considered in proportion to the water stored at low matric suctions, e.g. from 100 to 0 cm water. In the layers underneath the ploughed layer the unmeasured drainable pore space is up to 37 per cent of the measured pore space. In the ploughed layer this value is even up to 67 per cent. So a correct measurement of the water content at matric suction $= 0$, for instance with the "lid = bottom method" as introduced in this paper, can be of practical importance.

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SUMMARY

The water content at matric suction $= 0$ is not always found exactly by determining the soil moisture characteristic curve down to a suction of some centimeters (for instance 2.5 cm.), and extrapolating the curve down to a suction of zero. In soils with wide, clearly visible pores the water content found in this way can be too low. Therefore in this article a method is worked out to measure the water content at matric suction $= 0$ directly. This method comes down to the weighing of fully saturated cores.

The water content at matric suction $= 0$ determined by this method is equal to the porosity in unaerated soils. In top soils a considerable difference can occur between both values as a result of entrapped air.

RÉSUMÉ

La teneur en eau à une succion matricielle $= 0$ n'est pas toujours décelée exactement en déterminant la courbe caractéristique de de rétention de l'eau du sol jusqu'à une succion de quelques centimètres (par exemple 2,5 cm.) et en extrapolant la courbe vers le bas jusqu'à une succion de zéro.

Dans les sols à pores larges, clairement visibles, la teneur en eau trouvée de cette manière peut être trop basse. Aussi présente-t-on dans cet article une méthode élaborée pour mesurer directement la teneur en eau à la succion matricielle 0. Cette méthode revient à peser les échantillons complètement saturés.

La teneur en eau à la succion matricielle = 0 déterminée par cette méthode est égale à la porosité dans les sols non-aérés.

Dans les couches arables une différence considérable entre les deux valeurs peut survenir comme conséquence de l'air inclus.

ZUSAMMENFASSUNG

Der Wassergehalt bei einer Matrix-Saugspannung = 0 wird nicht immer genau ermittelt, indem man die charakteristische Kurve der Bodenfeuchtigkeit abwärts bis zu einer Saugspannung von einigen Zentimetern (z.B.2,5 cm.) bestimmt und die Kurve nach unten bis zu einer O-Saugspannung extrapoliert.

In Böden mit weiten, klar sichtbaren Poren kann der auf diese Weise ermittelte Wassergehalt zu gering sein. Deshalb wird in diesem Bericht eine ausgearbeitete Methode dargelegt, um den Wassergehalt bei einer Matrix-Saugspannung = 0 zu messen. Diese Methode geht dahin die vollkommen gesättigten Bodenmonolithe abzuwägen.

Der durch diese Methode bestimmte Wassergehalt bei einer Matrix-Saugspannung = 0 ist gleich der Porosität der undurchlüfteten Böden. Bei den Ackerkrumen kann zwischen den beiden Werten eine beträchtliche Differenz als Folge der eingeschlossenen Luft vorkommen.

DISCUSSION

M. DE BOODT (Belgium). How did you extrapolate the suction curve? Was it on the normal pF curve? Good results were obtained in our laboratory by putting the pF values on a graph where in ordinate the intergrated values of the guassian distribution were placed and in abcis the pF curve. In doing so, a straight pF curve was obtained. The point where the curve crosses the ordinate gives you the moisture content by zero suction.

B. FOKKENS. I can imagine that extrapolating the suction curve in the way you mentined gives good results in older, ripened soils, in which the formation of wide cracks is a reversible phenomenon. In young polder soils, wide irreversible cracks occur beside very small pores between the primary clay particles. In this case the cracks mean a jump in the pore size distribution, that cannot be found by extrapolation. The same is true when holes occur made by roots or soil animals, or as a result of tillage.

J. W. HOLMES (Australia). The water content of soils at a matric suction of zero is very easily changed by the manipulationx of specimen, such as compression, which may change the volume of the very large pores and press out some of the waterl Soils in place in field experience isan overburden pressure which is determined by the location of the specimen in the profile. The swelling of clay soils must take place against such an overburden pressure. Does the method that Mr. Fokkens described reproduce these natural restraints?

B. FOKKENS. Our method to measure the water content at matric suction = 0 allows free swelling of the cores. So, in weighing the artificially saturated cores at suction = 0 the real water content in the field is not measured, because in the last situation the swelling will be less indeed. We give a 100 percent correction for the free swelling, so that the water content we calculate is the water content in case no swelling at all occurs. When the suction curves are used to determine the total pore space or the pore size distribution in the field at the moment of sampling, this procedure is respectively correct and relatively correct. In fact this is mainly the aim of our research work. When suction curves are determined to find for instance the drainable pore space in practice, the cores ought to have a certain load, depending on the depth in the soil profile and the type of overlying soil. Until now we do not practice this in our laboratory.

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LE pF DE QUELQUES SOLS MÉDITERRANÉENS SON INCIDENCE EN IRRIGATION

J. R. DESAUNETTES [1]

PRÉAMBULE

La connaissance des doses d'arrosage des différents sols d'un périmètre d'irrigation est indispensable à la structuration des réseaux de distribution. Ce qu'il importe de connaître en pareil cas est la dose maximum admissible (Desaunettes, 1963), quantité maximum d'eau que le sol est susceptible de recevoir en fonction de sa capacité de rétention et de sa profondeur utile.

Depuis 1956, la détermination systématique de cette dose maximum a été entreprise au Bas-Rhône et Languedoc (France), sur la base d'une formule proposée par J. Bourrier (1954) :

$$\text{Dose en m}^3/\text{ha} = 0{,}3 \times \Delta a \times He \times h,$$

où Δa est la densité apparente du sol, He la valeur de l'humidité équivalente, h la profondeur utile du sol.

Cette formule admet que l'humidité au point de flétrissement (Pf), soit un pF de 4,2, représente les 55% de celle de l'humidité équivalente (He), soit un pF de 3.

La mesure directe de l'eau disponible entre pF 3 (He) et pF 4,2 (Pf) est une meilleure solution, mais elle réclame du temps et un appareillage spécial dont la manipulation exige beaucoup de soins. Aussi l'étude du pF des principales séries cartographiées au Bas-Rhône n'a-t-elle pû être entreprise qu'en 1963, et les données acquises avec leurs conclusions figurent l'objet de cette note.

SOLS ETUDIÉS

On indiquera successivement la groupe — la famille — éventuellement la série et la correspondance (approximative) avec la 7ème Classification américaine.

1. *Sols pas ou peu évolués*

11. Sols bruts de sables dunaires (Psamments). Il s'agit de dunes littorales constituées de sables moyens calcaires sans aucune évolution.
12. Sols alluviaux à tendance brun calcaire (Hapludents-eutrochrept). Ce sont des limons de l'Hérault, assez riches en humus dans le *A*.

[1] Compagne du Bas-Rhône et Languedoc, FRANCE.

13. Sols colluviaux des mollasses sableuses de l'helvétien (Hapludents). Sable fin limoneux et calcaire, profil clair, peu structuré et peu évolué.
14. Sols bruts d'érosion sur mollasses sableuses (Hapludents). Situés au dessus des précédents dans la catena, on a affaire à des sols rajeunis par l'érosion et généralement plus calcaires que ceux-là en raison de la mise à nu d'un ancien horizon d'accumulation calcaire.

2. *Sols moyennement évolués ou évolués*

21. Sol rendzinique sur sables astiens (Rendoll) Les sables fins calcaires sous forêt méditerranéenne à quercus ilex donnent un sol à épipédon mollique (structure grenue assez bien développée).
22. Rendzine brunifiée sur marnes sableuses plaisanciennes (Rendoll eutrochareptique). Cultivée, la rendzine se dégrade en sol brun calcaire à structure polyédrique.
23. Sol brun calcaire sur sables astiens } Eutrochrepts
24. Sol brun calcaire sur marnes sableuses plaisanciennes } plus évolués
25. Hydromorphe calcimorphe (Aquert) Sol hydromorphe présentant un *B* d'accumulation calcaire par apport de nappe.
26. Génohydromorphe (Hapludoll aquentique et aquique).
    Sol foncé de dépression où les alluvions fines (limons argileux) et calcaires se sont hydromorphysées. La structure est souvent prismatique dans le *B* parfoi enrichi en calcaire par la nappe phréatique (calcimorphie). (Desaunettes, 1958).
27. Génohydromorphe salé (Hapludoll à horizons salique et natrique). A proximité de la mer, la nappe est souvent salée, et le sol évolue en sol salin et parfois en alkali astructuré.

3. *Sols évolués, en général polygéniques ou fossiles*

31. Sol brun calcaire à pseudogley (endohydromorphe) sur diluvium pliocène (Ustert).
    Le pliocène et le Quaternaire ancien ont épandu un ensemble de diluviums à galets sur diverses parties du Languedoc. Sous l'influence des climats successifs du pleistocène, ces diluviums ont évolué de façon variée. On observe en particulier l'existence d'une formation argileuse rougeâtre, décarbonatée ou recarbonatée, témoin d'anciennes surfaces quaternaires et qu'on appelle „Limon pliocène". Ici, il s'agit d'un limon fin argileux peu évolué (brun calcaire) dont l'absence de drainage interne crée des conditions d'hydromorphie particulières.
32. Paléosol châtain sur astien (Calcustoll relique).
    On peut y observer en particulier l'existence de krotovinas encroûtées et les caractéristiques assez nettes d'un sol steppique qui ne correspond évidement plus aux conditions du climat actuel (Rutten, Bouteyre et Vigneron, 1963).
33. Sols marrons sur diluvium quaternaire (Ustoll et Calcustoll).
    Le „Sol marron" (Guerassimov, 1956, et Boulaine, 1959) semble

correspondre actuellement au climat des diluviums argileux du quaternaire ancien. Le profil est peu ou pas calcaire, avec pseudomycelium et concrétions, de couleur marron avec une structure polyédrique très marquée.

34. Sol rouge sur diluvium pliocène (Rhodustalf).
Chaque surface sur diluvium correspond à un climat donné; on y observe assez fréquemment un sol rouge apparenté au sol rouge méditerranéen (Desaunettes et Vigneron, 1958).

35. Sol rouge lessivé sur diluvium loessifié. Série „Gress à gapan" (Rhodustalf).
Par endroits, le diluvium villafranchien a été recouvert de loess, le mélange des deux a donné un sol rouge — souvent lessivé à cause du grand pourcentage de galets — et dont le B argillique, rouge vif, constitue l'horizon de diagnostic.

36. Sol brun-rouge à croûte sur complexe pédimentaire (Rhodustalfs polygéniques).

37. Sol brun-rouge sur pliocène basaltique.
Formés dans des conditions analogues aux précédents (34 et 35), ils évoluent actuellement vers les mollisols avec apparition d'un épipédon mollique qui masque un peu leurs anciens caractères.

38. Paléosol podzolique (lessivé podzolique) sur villafranchien. „Gress caveran" (Typorthod alfique).
Sur diluvium pliocène à galets non loessifié, on peut observer un sol podzolique caractérisé par:
— Un horizon *A2* trés lessivé
— Un horizon *B* argillique (marmorisé en général)
— L'abondance des éléments grossiers (de 70 à 90%).

On retrouve ce type de sol sur plusieurs diluviums méditerranéens (Desaunettes, 1964), parfois conservés à l'état relique par une végétation adaptée, ou bien polygénisé s'il est mis en cultures.

MÉTHODES UTILISÉES

— L'humidité équivalente a été mesurée par centrifugation à 1 000 g et pendant 30 minutes des échantillons saturés après 48 heures d'immersion.

— Le pF 4,2 correspondant au point de flétrissement a été déterminé à la presse à membrane (Coleman et Marsh, 1961).

— Le pF 4,85 a été estimé par équilibre en atmosphère de tension de vapeur connue, selon la technique utilisée par Hallaire et Domergue (utilisation d'un psychromètre en étuve).

Tous les échantillons ont été analysés au moins en double, et pour chaque série de mesures, un couple de témoins a permis de vérifier sa conformité.

RÉSULTATS OBTENUS

Exprimés en pourcentage d'humidité à pF 3, 4,2 et 4,85, les résultats des différents échantillons sont exposés dans le tableau 1.

Tableau 1

Humidité à pF 3, 4,2 et 4,85 et rapports *Pf% He* et *He/Pf*

Sol	pF 3	pF 4,2	pF 4,85	*Pf%He*	*He/Pf*	Horizon
Brut de sables dunaires	8,0	2,4	0,84	30	3,34	
	5,0	1,7	0,18	35	3,00	
	5,0	1,4	0,17	28	3,54	
id.	9	3,1	0,86	34	2,80	
	7	1,5	0,40	21	4,40	
	6	1,4	0,30	23	4,30	
Alluvial (Hérault)	19	7,1	3,3	37	2,68	
	15	5,3	2,4	42	2,35	
	14	4,9	2,7	35	2,86	
id.	11	7,1	3,3	30	3,29	
	19	8,8	4,6	46	2,16	
	10	1,9	0,4	19	5,25	Sable pur
Colluvial d'helvétien	20	7,2	3,5	36	2,79	
	18	7,6	3,4	42	2,35	
	16	6,8	3,2	42	2,34	
Brut d'érosion (helvétien)	13	3,9	1,8	30	3,34	
	15	4,8	1,9	32	3,10	
	15	3,9	1,7	26	3,85	
Rendzinique (astien)	20	7,2	2,3	36	2,78	
	19	7,1	2,4	37	2,68	
	10	1,5	0,7	15	6,67	Sable géologique
Brun calcaire rendzinique (plaisancien)	24	9,7	3,8	40	2,47	
	21	6,7	2,7	32	3,11	
	22	7,0	2,8	32	3,12	
Brun calcaire (astien)	17	6,4	2,25	37	2,66	
	18	3,9	1,33	22	4,62	Sable peu différencié
Brun calcaire (plaisancien)	18	8,1	2,9	45	2,21	
	24	9,9	3,0	41	2,43	
	25	7,3	2,9	29	3,42	Marnes en place
Hydromorphe calcimorphe	30	16,6	5,2	55	1,81	
	33	17,6	5,3	53	1,99	
	30	14,0	4,0	47	2,14	Horizon très calcaire
Génohydromorphe	37	25,0	6,5	68	1,48	
	32	21,1	6,7	66	1,52	Très structuré
	33	23,2	9,6	70	1,42	
	59	33,6	13,0	57	1,67	Légèrement salé
Génohydromorphe salé	39	21,0	11,03	54	1,86	
	61	27,3	18,5	45	2,22	Structure diffuse
	61	27,8	18,3	45	2,20	
id.	35	12,8	4,5	37	2,74	
	41	21,4	8,5	52	1,92	id.
	68	30,4	17,5	45	2,24	

Tableau 1 (suite)

Sol	pF 3	pF 4,2	pF 4,85	*Pf%He*	*He/Pf*	Horizon
id.	42	21,1	8,4	50	1,98	
	60	29,7	18,9	50	2,02	id.
	70	37,9	25,1	54	1,85	
Brun calcaire endo-hydro (diluvium pliocène	21	8,7	4,5	41	2,41	
	23	10,0	5,1	44	2,30	
	26	13,2	6,7	51	1,96	Horizon réduit très structuré
Paléosol châtain (astien)	23	10,6	4,3	46	2,17	
	22	9,7	4,9	44	2,26	
	25	6,9	2,9	28	3,64	Sable astien
Sol marron (diluvium IV)	20	9,1	3,7	46	2,19	
	21	9,8	3,5	47	2,15	
	19	7,6	2,8	40	2,50	
	23	12,7	4,9	55	1,81	
	33	19,3	7,5	59	1,71	
id.	16	7,1	3,2	44	2,26	
	29	15,6	6,6	54	1,85	
	27	15,7	7,4	58	1,72	
id.	19	8,1	3,8	42	2,35	Horizon recarbonaté.
	19	8,9	4,6	47	2,14	
	25	13,4	7,0	54	1,87	id.
	27	15,3	8,1	57	1,74	
Sol rouge caillouteux (pliocène)	25	14,2	6,1	57	1,75	
	28	16,8	7,0	60	1,67	
	20	4,0	1,5	20	5,00	Calcaire pur (croûte)
Gress à gapan (sol rouge lessivé caillouteux sur villafranchien	15	5,1	1,7	34	2,94	
	15	4,2	1,5	28	3,54	
	23	12,5	6,2	54	1,84	Horizon très structuré (gapan)
Gress à gapan sur taparas (croûte calcaire)	21	10,3	5,1	49	2,04	
	25	15,00	7,8	60	1,67	
	19	4,45	1,8	24	4,28	Croûte calcaire
Brun rouge sur complexe pédimentaire	21	9,6	4,5	46	2,18	
	21	10,1	4,8	48	2,07	
	25	12,4	5,5	50	2,02	
	23	5,6	3,6	24	4,10	Brèche
Brun rouge sur pliocène	20	7,9	3,7	40	2,52	
	22	9,2	4,7	42	2,38	
	20	8,1	3,6	41	2,45	
	25	11,8	5,3	47	2,1	
Gress caveran (paléopodzol caillouteux sur villafranchien)	16	5,1	1,5	32	3,14	Horizon astructuré
	15	4,6	1,4	30	3,26	id.
	24	14,7	6,9	63	1,58	Horizon ancien très structuré
id.	16	5,6	1,4	35	2,86	Horizon très lessivé
	15	4,5	0,8	30	3,34	id.
	26	16,4	8,0	63	1,58	Paléohorizon argileux et structuré

On a également calculé le pourcentage: humidité à pF 4,2 par rapport à l'humidité à pF 3 (pF 4,2% pF 3) et le rapport humidité à pF 3 sur humidité à pF 4,2 (*He*/*Pf*).

Enfin on a signalé la nature des horizons remarquables et susceptibles de donner au rapport *He*/*Pf* une valeur particulière.

La moyenne des résultats obtenus est telle que l'humidité à pF 4,2 représente 45,1% de celle à pF 3, ce qui comparé au chiffre considéré dans ia formule (55%), implique une sousestimation de la dose de 20% environ.

L'humidité à pF 4,85 tombe à 21% de celle de l'humidité équivalente.

La droite de corrélation entre l'humidité au point de flétrissement, fonction de l'humidité équivalente a pour équation:

$$Y = 0{,}59\, X - 2{,}2$$

DISCUSSION DES RÉSULTATS

La représentation graphique (fig. 1) fait ressortir un fait important: les échantillons provenant des sols salés et des niveaux géologiques (sables, calcaires, tendres ou croûtes), sont nettement en dehors du nuage concrétisant la position des échantillons sur le graphique.

Ce résultat est dû sans aucun doute possible à la structure dont l'effet peut encore être mis en évidence par l'étude du rapport *He*/*Pf* (voir tableau 1), rapport qui est d'autant plus faible que l'horizon est plus structuré.

On est alors amené à établir la corrélation réduite aux échantillons non salés des horizons *A* et *B* uniquement.

Cette corrélation:

$$Y = 0{,}51\, X - 0{,}39$$

peut encore être améliorée en groupant les résultats par classes. On obtient alors une „courbe en *S*" (fig. 2), justifiable semble-t-il d'une fonction du troisième degré, et dont l'indice de corrélation est trés élevé: 0,99.

Une étude identique pour pF 4,85, sans grand intérèt pratique, montre que la courbe de corrélation à la même allure que la courbe pF 4,2 et qu'elle est située entre celle-ci et l'axe *OX* (*He*).

CONCLUSIONS

Les conclusions que l'on peut tirer de cette étude, limitées aux cas études, bien entendu, sont les suivantes:

— l'état structural a une grosse importance sur le pourcentage d'eau disponible, en relation sans aucun doute avec la porosité. Cela rejoint nos conclusions d'une étude précédente sur la rétention (Vigneron et Desaunettes, 1960);

— comme on s'y attendait, le calcul de la dose maximum d'arrosage d'après la formule citée ($D = 0{,}3.\ He\ .\ \Delta a\ .\ h$), conduit à une sousestimation

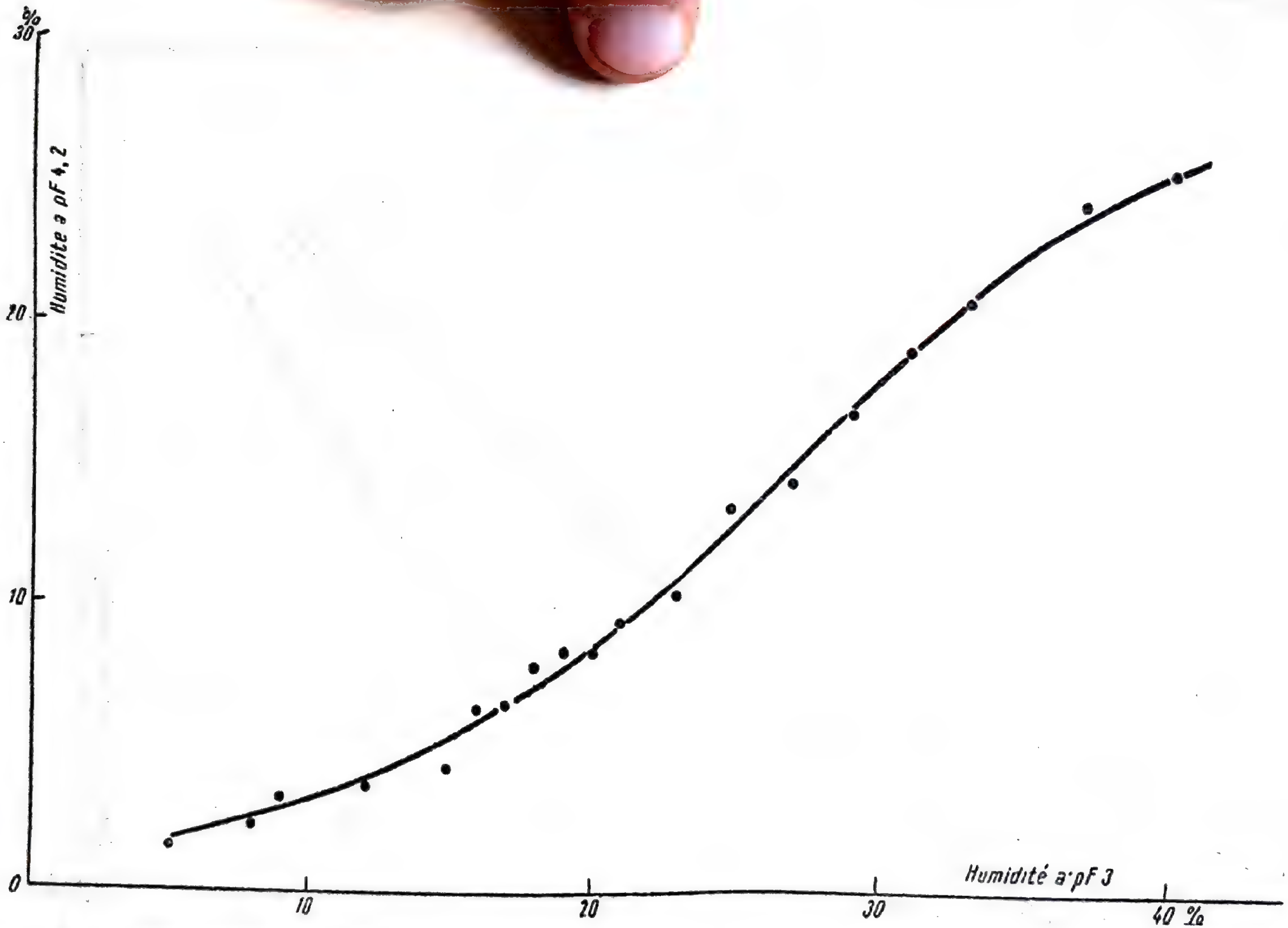

Fig. 2. Corrélation entre l'humidité à pF = 4,2 et l'humidité à pF = 3,0 réduite en groupant les résultats par cllasses.

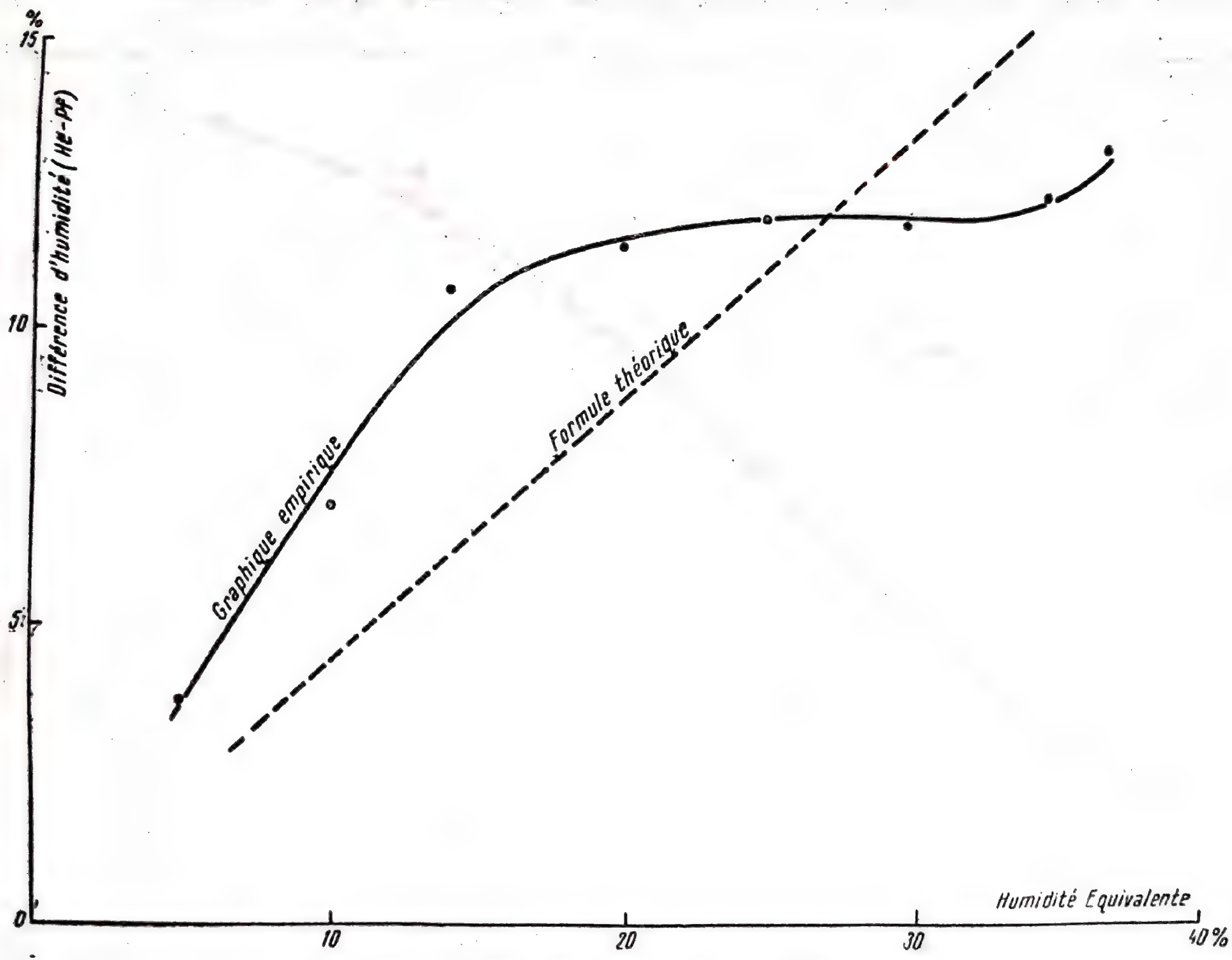

Fig. 3. Corrélation entre l'eau disponible et l'humidité équivalente.

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pour les sols légers et à une surestimation pour les sols lourds (Desaunettes, 1963).

Il convient donc soit de mesurer *He* et *Pf* séparément (prix de revient élevé), soit d'établir une courbe expérimentale $(He\text{-}Pf) = f(He)$ pour les différentes séries étudiées et de s'y référer (fig. 3).

Cette courbe montre, en ce qui concerne les échantillons de la corrélation réduite étudiée ici, qu'à partir d'une humidité équivalente de 15%, l'eau disponible augmente très peu, sauf pour les sols salés apparemment. Mais les sols salés constituent un cas spécial, car le point de flétrissement déterminé par voie physique (pF=4,2) est beaucoup plus haut que le *Pf* physiologique auquel s'ajoute la tension osmotique des sels solubles, diminuant d'autant l'eau disponible.

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RÉSUMÉ

La présente étude a montré que, pour certains sols du midi de la France, le rapport entre l'humidité à pF 3 (humidité équivalente) et l'humidité à pF 4,2 (point de flétrissement) n'était pas constant.

La relation : humidité à pF 4,2 en fonction de l'humidité à pF 3 n'est pas linéaire ; c'est une courbe en *S*.

L'importance de ce fait est très grande pour l'irrigation, car l'eau disponible pour les plantes (eau comprise entre pF 3 et pF 4,2) n'augmente plus à partir d'une humidité équivalente de 15%.

Par ailleurs, la structure du sol a une grande influence sur cette relation.

SUMMARY

This study points out — as far as the peculiar soils from the south of France analysed here are concerned — the variability of the ratio between soil moisture at pF 3 and that at pF 4.2.

In other words, the relation linking soil moisture at pF 4.2 to soil moisture at pF 3 is not linear, but complex *S* shaped curve).

This fact is very important for irrigation since the available water (difference in moisture between pF 3 and pF 4.2) does not increase with moisture equivalent beyond 15 per cent, except for saline soils.

Besides, the soil structure disclosed has a great effect on the relation : moisture at pF 4.2 as related with moisture at 3.

ZUSAMMENFASSUNG

Diese Abhandlung zeigt für bestimmte Böden Südfrankreichs, dass das Verhältnis von Feuchtigkeit zu pF 3 (äquivalente Feuchtigkeit) und der Feuchtigkeit zu pF 4,2 (Welkepunkt) nicht beständig ist.

Die Relation : Feuchtigkeit bei pF 4,2 in Abhängigkeit von der Feuchtgkeit bei pF 3 ist nicht linear ; es ist eine Kurve in *S*.

Diese Tatsache ist sehr wichtig für die Bewässerung, da das verfügbare Wasser für Pflanzen (Wasser zwischen pF 3 und pF 4,2) von einer äquivolenten Feuchtigkeit von 15%. nicht mehr ansteigt.

Die Bodenstruktur hat andererseits einen grossen Einfluss auf diese Relation.

DISCUSSION

F. F. R. KOENIGS (Pays-Bas). En centrifugeant un échantillon saturé d'un centimètre de hauteur à 1 000 g, la succion varie de 1 000 cm à la surface jusqu'à zero à la base. La succion moyenne est donc plus basse que pF 3.

J. R. DESAUNETTES. Pour tenir compte de ce fait inévitable, une table de correction permet de rectifier les valeurs des humidités trouvées à l'étuve après centrifugation.

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CONTRIBUTIONS À LA DÉTERMINATION INDIRECTE DE LA CAPACITÉ EN EAU AU CHAMP

E. MOŢOC, A. CANARACHE, R. DUMITRIU [1]

La capacité en eau au champ demeure l'un des principaux indices hydrophysiques conditionnant une correcte mise en œuvre de l'irrigation, malgré toutes les critiques auxquelles cette notion a été récemment soumise du point de vue théorique et méthodologique (Richards, 1960). Les difficultés rencontrées pour la détermination directe sur le terrain nuisent sensiblement à son utilisation en pratique, agissant ainsi négativement sur l'application et la planification de l'eau d'arrosage. On a effectué, par suite, de nombreux essais d'appréciation indirecte de la capacité en eau au champ, en se servant, dans ce but, de corrélations avec l'humidité équivalente (Veihmeyer et Hendrickson, 1931 ; Browning, 1941), l'humidité correspondant à une force de succion d'environ 1/3 d'atmosphère (Richards et Weaver, 1946), 1/10 d'atmosphère (Haise, Haas et Jensen, 1955), 0,06 d'atmosphère (Carlson, 1959), ou la texture (Dolgov, 1948 ; Chichkov, 1957 ; Wilcox et Spilburry, cités par Rodé, 1952). Les corrélations entre les différentes propriétés physiques et la capacité au champ ont été également établies pour certains sols de Roumanie (Canarache, 1964 ; Dumitriu, 1964 ; Moţoc, 1964).

On considère généralement que ces corrélations ont un caractère fortement conventionnel, dû à certaines causes méthodologiques et à de multiples facteurs qui influencent la capacité en eau au champ dans des conditions de terrain. C'est pourquoi on rencontre rarement dans la littérature soviétique des appréciations indirectes sur la capacité en eau au champ ; la préférence va à la détermination directe. Les auteurs américains mentionnent dans les bulletins d'analyse les valeurs de l'humidité équivalente ou de l'humidité à 1/3 atmosphères comme telles, sous-entendant comme étant correspondantes à la capacité en eau au champ.

La présente étude traite de certaines corrélations qui sont utiles pour l'appréciation indirecte de la capacité en eau au champ.

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On a utilisé les résultats obtenus sur environ 180 profils de sols zonaux, variant par rapport au type génétique et à la roche de solification. La capacité en eau au champ a été déterminée sur le terrain, après application d'une quantité d'eau suffisante pour humidifier le profil à une profondeur de 2 m. On a prélevé des échantillons 36-48 heures après l'infiltration de l'eau appliquée. La composition granulométrique a été déterminée sur des échantillons préparés d'après la méthode Katchinski ; dans la présente étude on n'a utilisé que les résultats relatifs à la teneur en argile (moins de 0,002 mm de diamètre) et en argile physique (moins de 0,01 mm de diamètre). Le coefficient hygroscopique a été déterminé d'après Mitscherlich, la capacité moléculaire maxima pour l'eau (suivant Lebedev) pour une pression de 100 kg/cm^2 et l'humidité équivalente, suivant Briggs et Mac Lane. Le poids volumétrique a été déterminé au cylindre de 100 cm^3.

Les résultats analytiques, obtenus initialement par horizons génétiques ont été recalculés sous forme de moyennes et de réserves d'eau pour les couches 0—50, 0—100 et 0—150 cm, procédé offrant des résultats plus synthétiques et plus adéquats pour les cultures irriguées.

Les profils examinés ont été groupés par rapport aux caractéristiques génétiques : le type (sous-type) génétique du sol et la roche de solification (correspondant à certains secteurs geographiques déterminés). Les corrélations recherchées ont été calculées tant pour chacun des groupes séparés que pour l'ensemble de tous les profils étudiés.

RÉSULTATS ET DISCUSSION

Le tableau 1 présente les coefficients de corrélation entre la capacité en eau au champ et les autres propriétés physiques déterminées pour les 3 profondeurs considérées du profil. De leur comparaison il résulte en général que l'on obtient des corrélations plus serrées sur l'épaisseur de 100 cm, c'est à dire sur l'épaisseur moyenne considérée. Le fait est explicable compte

Tableau 1

Coefficients de corrélation de la capacité en eau au champ pour tous les sols étudiés (à l'exception des sols du Plateau Gétique) pour diverses profondeurs

Profondeur (cm)	Coefficients de corrélation entre :						
	CC (%)		*CC* (mm)				
	A	*Ap*	*A*	*Ap*	*CH*	*CMM*	*HE*
0—50	+0,328	+0,258	+0,426	+0,445	+0,569	+0,450	+0,567
0—100	+0,244	+0,331	+0,614	+0,637	+0,657	+0,695	+0,657
0—150	+0,173	+0,100	+0,421	+0,447	+0,449	+0,488	+0,683

Explication des symboles: *CC*(%) — capacité en eau au champ (% du poids); *CC* (mm) — — capacité en eau au champ (mm de colonne d'eau); *A* — argile (%); Ap — argile physique (%); *CH* — coefficient hygroscopique (%); *CMM* — capacité moléculaire maxima pour l'eau (%); *HE* — humidité équivalente (%).

tenu, d'une part, de l'influence modificatrice de l'état de culture du sol sur les résultats obtenus dans les horizons supérieurs et, d'autre part, des erreurs plus grandes de la détermination de la capacité au champ à des profondeurs excédant 100 cm.

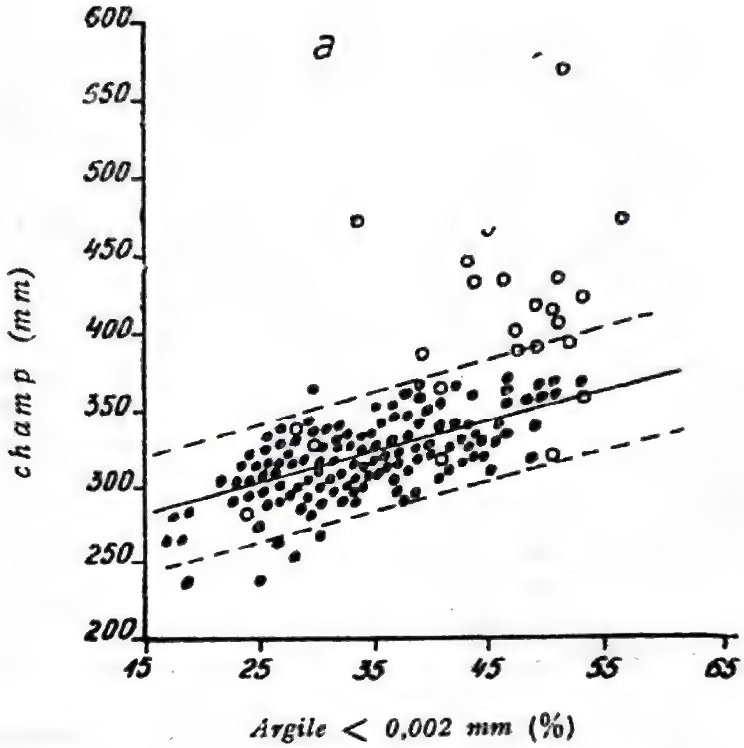
Si l'on examine les coefficients de corrélation obtenus par groupes de sols séparés (tableau 2), on trouve d'importantes variations d'un groupe à l'autre. Ces variations sont dues au nombre différent de profils composant les divers groupes de sols et spécialement au domaine différent des valeurs des propriétés considérées. La position sur le graphique des groupes de sols (fig. 1), de même que les équations de régression calculées par groupes de sols (non représentées dans la présente étude) démontrent que parmi les groupes de sols, il y en a un qui présente des différences sensibles, celui des sols du type smonitza, partiellement podzolisés, et des sols podzoliques. Les points sur le graphique, relatifs à tous les autres groupes de sols, ont pu être réunis en calculant une seule équation linéaire de régression (tableau 3). La position particulière du nuage de points concernant les profils des sols formés sur les argiles du Piémont Gétique est due soit à leur texture plus argileuse, soit à la variation sur le profil, caractéristique des sols podzolisés, de la texture et des autres propriétés considérées.

Quelle que soit l'explication et compte tenu du nombre réduit de profils appartenant à ce groupe de sols, ils ont été éliminés des calculs de corrélation dont les résultats sont exprimés dans le tableau 3.

Parmi les corrélations susdites, celles qui ont été établies entre la teneur en argile et la capacité au champ constituent un argument puissant en faveur des avis de nombreux auteurs — mais combattus par d'autres — qui soutiennent l'existence d'une étroite dépendance entre la capacité au champ et la texture. En ce qui concerne les corrélations basées sur l'humidité équivalente, valeur dont on se sert depuis longtemps pour l'appréciation indirecte de la capacité au champ, la forme adoptée pour l'exprimer — celle d'une équation linéaire de régression — présente l'avantage de permettre une telle apréciation aussi en dehors de l'intervalle à l'intérieur duquel les valeurs de l'équivalent d'humidité et de capacité au champ coïncident.

Les équations de régression du tableau 3 peuvent servir en pratique. Les erreurs qu'elles pourraient entraîner dans l'appréciation de la capacité au champ sont de l'ordre de 4% (par rapport au poids), respectivement de 30—40 mm de colonne d'eau; ces erreurs peuvent être considérées comme acceptables. L'établissement de plusieurs méthodes d'appréciation de la capacité au champ, basées sur différentes propriétés du sol, doit être considéré comme utile, donnant ainsi aux différents laboratoires diverses possibilités pour déterminer les propriétés du sol nécessaires à l'application de ces méthodes.

En comparant, dans les tableaux 2 et 3, l'efficacité des corrélations établies pour l'appréciation indirecte de la capacité au champ à l'aide des données des différentes propriétés déterminées (teneur en argile, coefficient hygroscopique, capacité moléculaire maxima pour l'eau, humidité équivalente), on constate que les valeurs sont sensiblement rapprochées. Si l'on tient compte également des valeurs élevées des coefficients de corrélation



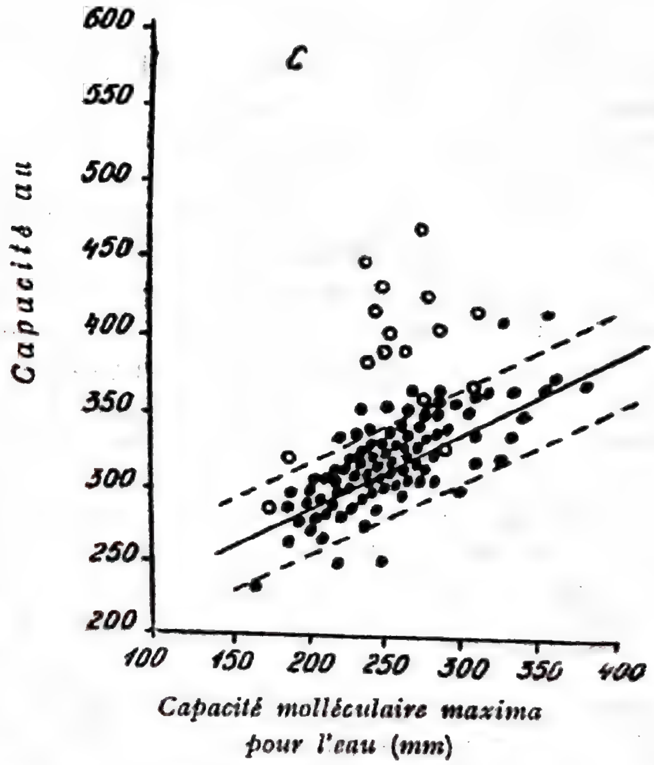
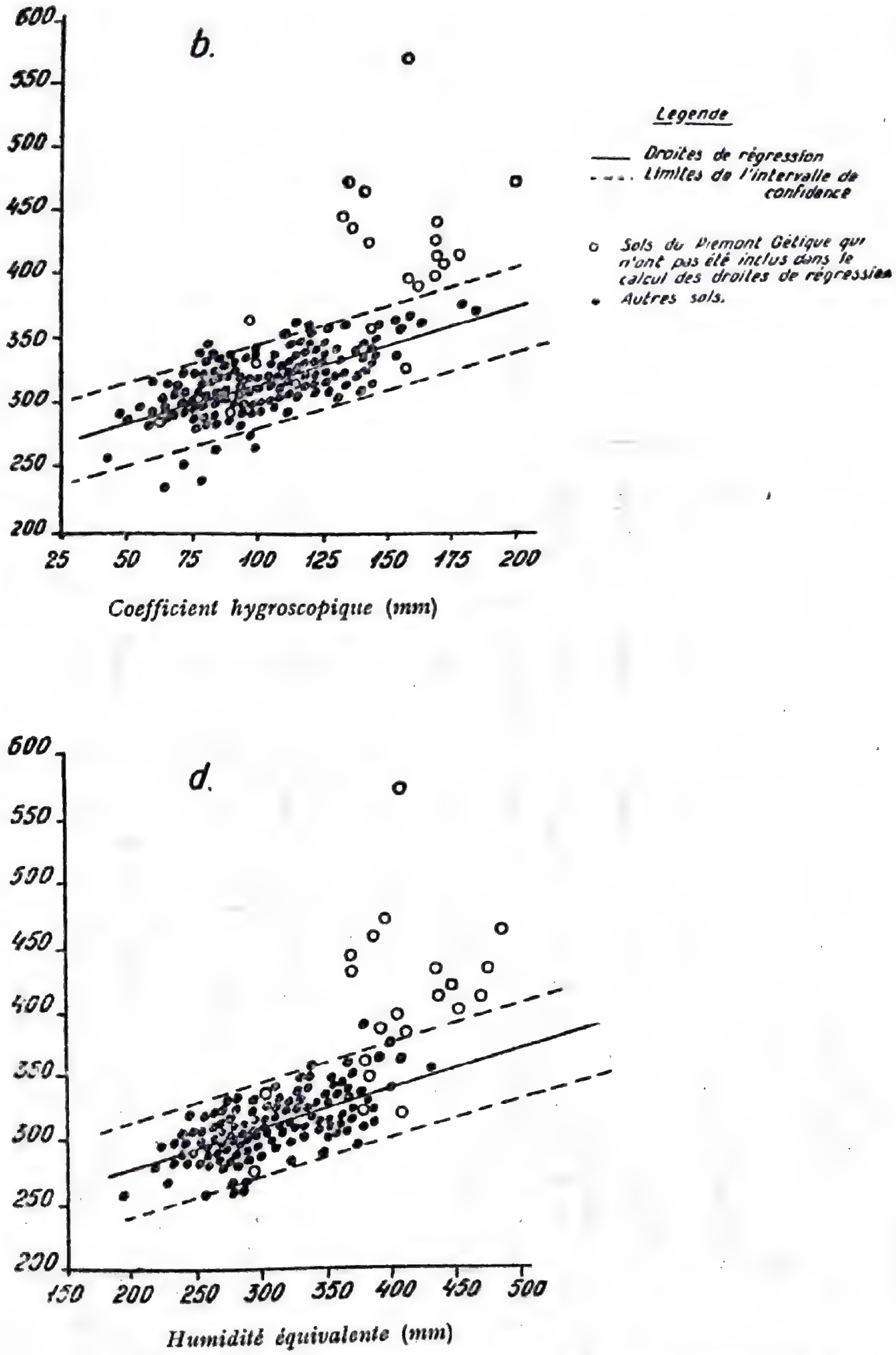


Fig. 1. Corrélations de la capacité en eau au champ
a — corrélation pour la teneur en argile;
c — corrélation pour la capacité moléculaire maxima pour l'eau;



pour tous les sols étudiés, pour la profondeur 0—100 cm :
b — corrélation pour le coefficient hygroscopique.
d — corrélations pour l'humidité équivalente.

Tableau 2

Coefficients de corrélation de la capacité en eau au champ par groupes de sols, pour la profondeur 0–100 cm.

Sols considérés	Nombres des profils étudiés	Coefficients de corrélation entre :						
		CC (%)		*CC* (mm)				
		A	*Ap*	*A*	*Ap*	*CH*	*CMM*	*HE*
Sols groupés selon le type (soustype) génétique								
Sols châtains de steppe et chernozems	57	+0,378	+0,426	+0,540	+0,519	+0,588	+0,571	+0,666
Chernozems faiblement et moyennement lévigués	49	+0,518	+0,561	+0,556	+0,557	+0,634	+0,744	+0,662
Chernozems fortement et très fortement lévigués	28	+0,717	+0,813	+0,603	+0,688	+0,698	+0,610	+0,352
Sols bruns-roux de forêt	23	+0,753	+0,771	+0,618	+0,698	+0,652	+0,613	+0,647
Smonitzas et sols podzoliques	22	+0,637	+0,651	+0,419	+0,414	+0,545	+0,660	+0,520
Sols groupés selon le secteur géographique (la roche mère)								
Dobroudja et Munténie de l'est (loess et matériaux loessoïdes)	107	+0,134	+0,204	+0,590	+0,588	+0,639	+0,686	+0,647
Munténie de l'ouest (limons et limons-argilex)	28	+0,511	+0,612	+0,552	+0,657	+0,653	+0,585	+0,746
Olténie (limons, souvent avec une haute teneur en sable grossier)	22	+0,763	+0,808	+0,669	+0,708	+0,745	+0,725	+0,773
Plateau Gétique (argiles)	22	+0,637	+0,651	+0,419	+0,414	+0,545	+0,660	+0,520

Pour l'explication des symboles, voir le tableau 1.

Tableau 3

Corrélations pour tous les sols étudiés (à l'exception des sols du Plateau Gétique) pour la profondeur 0–100 cm

Équation de régression	Coefficient de corrélation
$CH = -4 + 3{,}20\,A$	+0,986
$CMM = 96 + 3{,}43\,A$	+0,763
$HE = 122 + 5{,}72\,A$	+0,835
$CC(\%) = 21 + 0{,}063\,A$	+0,244
$CC(\%) = 20 + 0{,}072\,Ap$	+0,331
$CC(\text{mm}) = 247 + 1{,}98\,Ap$	+0,614
$CC(\text{mm}) = 230 + 1{,}75\,AA$	+0,637
$CC(\text{mm}) = 253 + 0{,}58\,CH$	+0,657
$CC(\text{mm}) = 212 + 0{,}47\,CMM$	+0,695
$CC(\text{mm}) = 219 + 0{,}30\,HE$	+0,657

Pour l'explication des symboles, voir le tableau 1.

entre la teneur en argile et les indices hydrophysiques déterminés, on peut conclure que la corrélation entre ceux-ci et la capacité au champ ne représente, en fait, qu'une forme particulière pour exprimer la corrélation, plus générale, entre la teneur en argile (texture du sol) et la capacité au champ. Ainsi, on peut s'attendre à ce que les autres propriétés du sol, qui sont reliées à la texture puissent aussi servir à l'appréciation indirecte de la capacité au champ.

En ce qui concerne les corrélations de la capacité au champ avec les deux fractions argileuses considérées, on constate une certaine tendance d'augmentation du coefficient de corrélation dans le cas de l'argile physique. Cela peut s'expliquer par l'influence plus marquée que pourraient avoir les fractions granulométriques plus grossiéres sur la capacité au champ; ce fait correspond dans une certaine mesure, aux conclusions de Jamison et Kroth (1958). Il est possible que l'extension des corrélations de la capacité au champ à d'autres fractions granulométriques apporte, dans ce sens, des résultats intéressants.

La comparaison des valeurs des coefficients de corrélation pour la teneur en argile, dans le cas où la capacité au champ est exprimée sous forme gravimétrique (pourcetages de poids) ou volumétrique (en mm de colonne d'eau) est spécialement intéressante. Dans l'ensemble, les corrélations sont plus serrées si l'on emploie la seconde forme d'expression. Le caractère plus ou moins serré des corrélations en rapport du mode d'exprimer la capacité au champ diffère essentiellement pour les groupes de sols séparés (tableau 2). Les deux premiers des groupes séparés d'après le type génétique, de même que les deux premiers groupes séparés d'après la roche de solification, sont caractérisés par l'augmentation du coefficient de corrélation, tandis que pour les autres groupes de sols, le fait d'exprimer sous forme volumétrique, la capacité au champ ne modifie pas et même diminue le coefficient de corrélation. Les faits qui précèdent ont été partiellement mis en évidence pour les sols formés sur loess par Obrejanu et al. (1961), et ils ont été expliqués par la variation dans le même sens que présentent la teneur en ar-

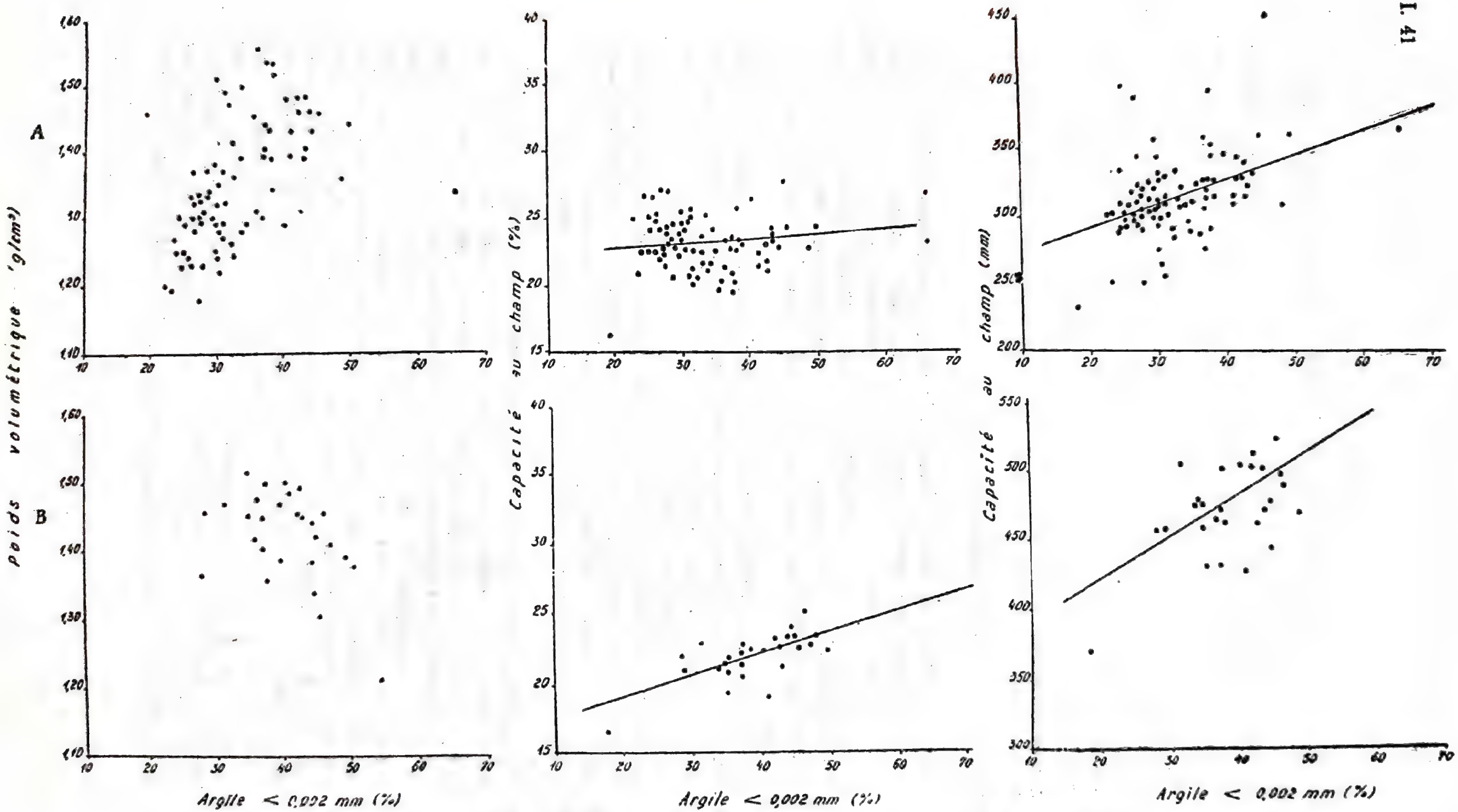


Fig. 2. Corrélations entre la teneur en argile, le poids volumétrique et la capacité en eau au champ: *A* — pour les sols formés sur loess et sur matériaux loessoïdes (profondeur 0—100 cm); *B* — pour les chernozems fortement et très fortement lévigués (profondeur 0—150 cm).

gile et le poids volumétrique des sols de la série génétique, commençant par les chernozems et finissant par les sols bruns-roux de forêt. Cette explication est confirmée par les données de la figure 2. Pour les groupes de sol où la situation est inverse, l'explication réside probablement dans la variation en sens inverse de la teneur en argile et du poids volumétrique.

CONCLUSIONS

1. Nous avons fait ressortir un ensemble de corrélations, à l'aide desquelles il est possible d'apprécier de façon satisfaisante la capacité au champ. Il y a des indices que les différentes corrélations étudiées représentent en fait une forme d'exprimer l'influence de la texture sur la capacité au champ.

2. Les corrélations établies se distinguent par rapport au type génétique du sol et de la roche de solification, le groupement des sols considérés sous ces aspects (et éventuellement l'élimination de certains groupes séparés) s'avérant nécessaire à l'occasion de semblables calculs de corrélations.

3. Il existe des relations complexes, différentes par raport aux conditions de pédogenèse, entre la teneur en argile, le poids volumétrique et la capacité au champ. L'existence d'une corrélation plus étroite entre la teneur en argile et la capacité au champ, exprimée sous forme gravimétrique ou volumétrique, dépend de la nature de ces relations.

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RÉSUMÉ

Pour déterminer la capacité en eau au champ, on a établi des corrélations entre les différentes propriétés physiques du sol et la capacité en eau au champ. On a utilisé dans ce but le matériel analytique obtenu pour environ 180 profils de sol, variant d'après le type génétique et la roche de solification.

Ces corrélations ont été calculées tant par groupes de sols distincts que pour l'ensemble de tous les profils étudiés.

Les résultats obtenus indiquent qu'il existe, entre la teneur en argile, le poids volumétrique et la capacité en eau au champ, des relations complexes. Quant aux corrélations établies par rapport aux différentes propriétés physiques, elles représentent en fait une forme d'exprimer l'influence de la texture sur la capacité au champ.

SUMMARY

For the determination of field capacity, correlations between different soil physical properties and field capacity were calculated. Analytical data, concerning about 180 zonal soil profiles, varying as to soil groups and parent material were used.

These correlations were calculated for distinct soil groups as well as for all soil profiles investigated.

The results showed the complexe relationship existing between clay content, volume weight and field capacity. The correlations calculated for different soil physical properties are expressing the influence of soil texture on field capacity.

ZUSAMMENFASSUNG

Für die Bestimmung der Wasserfeldkapazität wurden Korrelationen zwischen den verschiedenen physikalischen Bodeneigenschaften und der Feldkapazität festgesetzt. Zu diesem Zweck wurden ungefähr 180 Bodenprofile unterschiedlich nach genetischen Bodentyp und Muttergestein, verwendet.

Diese Korrelationen wurden sowohl gruppenweise als auch als Gesamtheit der Profile untersucht.

Die Befunde erweisen, dass zwischen Tongehalt, Volumengewicht und Feldkapazität komplexe Beziehungen bestehen. Die festgelegten Korrelationen zu den verschiedenen physikalischen Eigenschaften stellen in Wirklichkeit eine Ausdrucksform des Textureinflusses auf die Feldkapazität dar.

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UNE MÉTHODE DE LABORATOIRE POUR LA DÉTERMINATION DE LA CAPACITÉ AU CHAMP

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I. INTRODUCTION

Avant de mesurer la capacité au champ, il convient de définir cette grandeur. Ce problème se pose depuis quelque temps et pour certains auteurs (Richards, 1960) le concept même de capacité au champ n'a pas de sens. Pour d'autres cependant, il existe bien pour chaque sol une certaine valeur de l'humidité qui est relativement constante dans le temps. En effet pour Rodé (1960) des déterminations périodiques de l'humidité en place mettent en évidence l'existence d'une telle valeur. Elle apparaît notamment, en l'absence de nappe, pendant la période où le sol est abondamment alimenté en eau par les pluies. Nous avons utilisé (Feodoroff, 1965) la méthode préconisée par Rodé et avons constaté qu'effectivement pour chaque horizon considéré, en période humide, il existe une valeur caractéristique moyenne de l'humidité nettement distincte de la saturation totale. Les différentes mesures oscillent autour de cette valeur moyenne avec une erreur standard faible, inférieure à 0,30 pour les terrains étudiés. On retrouve donc de cette façon, en période hivernale ou printanière, la valeur de la capacité au champ.

Le problème se pose différemment en été, lorsque le sol est relativement sec. A l'issue d'une pluie ou d'un arrosage, et en l'absence de l'évaporation, l'eau du sol est soumise à la redistribution qui se manifeste par sa pénétration en profondeur et par l'abaissement de l'humidité en fonction du temps pour un même niveau. Suivant les auteurs, ou bien il apparaît une valeur relativement constante de l'humidité, et alors on parle de capacité au champ, ou bien cette valeur n'apparaît pas avec le mode d'expression utilisé, comme c'est le cas pour Ogata et Richards (1957).

Cependant, l'un de nous a montré (Feodoroff, 1962) par des essais de redistribution au laboratoire dans des colonnes de terre, qu'il existe bien à chaque niveau une valeur de l'humidité à partir de laquelle le drainage *se ralentit*, ce qui rejoint des observations analogues de Dolgov (1948).

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Ce ralentissement est parfois, mais pas toujours, masqué par l'expression des résultats avec une échelle logarithmique, ce qui explique peut-être l'interprétation d'Ogata et Richards.

Il apparaît de plus, dans des essais que nous avons effectués, que quelques facteurs extérieurs au sol (intensité et dose de l'arrosage) ont un effet certain sur l'allure générale de la redistribution, et notamment sur son évolution dans le temps. Dans ces conditions il est bien entendu illusoire d'identifier à la capacité au champ l'humidité du sol en place, par exemple, 24 h ou 48 h après une pluie ou un arrosage. C'est là qu'il faut voir, nous semble-t-il, la cause d'un certain nombre d'échecs pour mesurer la capacité au champ en place.

Néanmoins, on peut retenir à la suite des essais précédemment cités qu'il existe bien une certaine valeur caracteristique de l'humidité du sol en place. Au dessous de cette valeur, soit la redistribution se ralentit, soit le drainage est négligeable. La connaissance de cette humidité particulière, qui est la capacité au champ, présente un intérêt certain pour tout aménagement d'hydraulique agricole.

Comme la mesure en place est longue et peu commode, on a cherché à la remplacer par des mesures au laboratoire. Il a beaucoup été question de considérer que la capacité au champ correspond à un pF déterminé, mais des faits expérimentaux récents (Marshall et Stirk, 1949 ; Combeau et Quantin, 1963 ; Gras, 1962) montrent qu'il n'existe pas une valeur unique de pF caractérisant la capacité au champ de sols différents. Il nous a donc semblé utile de chercher une nouvelle méthode pour mesurer cette grandeur au laboratoire.

II. LA MÉTHODE EXPÉRIMENTALE

A. *Principe*

La méthode consiste à reproduire au laboratoire, d'une façon accélérée le phénomène de redistribution avec des échantillons remaniés. On obtient ainsi pour un sol donné une courbe expérimentale $h = f(t)$, où h est l'humidité en % de poids, et t le temps. Pour chaque intervalle de temps expérimental, on calcule $\Delta h / \Delta t$. Les valeurs conventionnellement positives ainsi obtenus sont portées en ordonnée sur un graphique où les humidités moyennes h' de l'intervalle considéré sont portées en abscisse. La capacité au champ correspond à un point particulier de la courbe, ce qui résulte de la confrontation de mesures au champ et de mesures au laboratoire.

B. *Description du procédé expérimental*

Le sol sec tamisé à 2 mm est introduit dans des tubes en verre de 3 cm de diamètre et 10 cm de haut. Ces tubes sont fermés à leur partie inférieure par une gaze en nylon. Le remplissage est fait par plusieurs prises successives, de façon à ce qu'il soit homogène. On tapote légèrement le tube sur la paillasse

au cours de cette opération. On arrête lorsque la terre remplit les 4 cm inférieurs.

Puis cette colonne de terre est humectée par remontée capillaire à partir d'un plan d'eau constant. Le tube plonge de 0,5 cm environ dans l'eau. Lorsque le front a atteint la surface de la terre, on place le tube sur une masse plus importante de la même terre, mais séchée à l'air, contenue dans un bécher de 250 cm³.

Pour assurer un meilleur contact entre la colonne de terre humide et son support de terre sèche, on introduit après humectation, dans la partie supérieure du tube, un bâton en matière plastique rigide de longueur telle qu'il ne tasse pas la terre, mais la maintienne. L'orifice supérieur du tube est ensuite coiffé avec un capuchon imperméable en tissu plastique. L'ensemble du tube ainsi monté est appliqué énergiquement sur la terre sèche, et maintenu ensuite solidaire du bécher par un fort caoutchouc (fig. 1).

Fig. 1. Dispositif expérimental.

Ainsi l'eau contenue initialement dans la colonne supérieure passe progressivement dans le support de terre sèche sous l'effet des forces de gravité et de succion, mais absolument à l'abri de l'évaporation.

Pour chaque sol étudié, une série de tubes permet de faire des prélèvements d'humidité échelonnés dans le temps, chaque tube étant sacrifié. L'humidité est déterminée sur une carotte de 1 cm² de section environ et de longueur égale à la colonne de terre. Après passage à l'étuve à 105°, on calcule l'humidité moyenne h' de la colonne au temps voulu.

C. *Remarques concernant le procédé expérimental*

L'idée de ce procédé expérimental est empruntée à Dolgov (1948), Richards et Moore (1952) l'ont également utilisé.

Ce procédé est équivalent à la redistribution dans des grandes colonnes de terre partiellement humectées par le haut, mais plus rapide, car le rapport

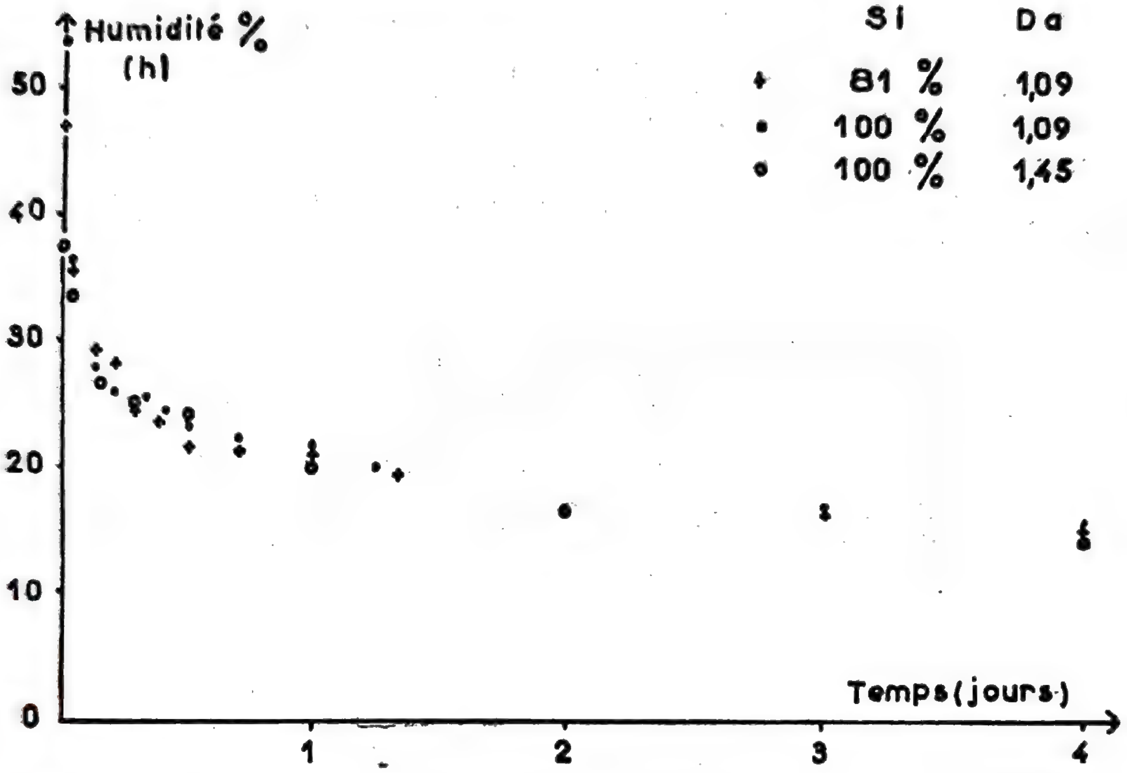

Fig. 2. Sol limono-argileux. Influence de la préhumectation et du compactage: *Si* — saturation initiale % ; *Da* — densité apparente g/cm³.

terre humide/terre sèche est environ 1/6 (Feodoroff, 1962). En effet, nous avons contrôlé que l'humidité du substrat immédiatement sous la toile du tamis s'accroît d'abord très rapidement, puis devient égale à celle de la colonne de terre. Il y a donc continuité entre la colonne et le substrat, et le système peut être valablement assimilé à une colonne unique.

Cette méthode ne permet pas de travailler avec un seul tube. En effet une fois que la terre a perdu une partie de son eau, il n'est plus possible de faire adhérer correctement le tube à son support après avoir effectué une pesée.

De plus nous avons cherché à préciser un certain nombre de points relatifs au protocole expérimental.

1. *La préhumectation initiale* telle que nous l'avons pratiquée produit une saturation incomplète de l'échantillon, comprise entre 85 et 100% suivant les cas. Nous avons cherché si en amenant l'échantillon à saturation totale, les courbes $h = f(t)$ et $\Delta h/\Delta t = f(h')$ sont modifiées. Les essais pratiqués sur un des sols étudiés (fig. 2) montrent que ce facteur n'a pas d'influence visible.

2. *Le compactage* de la terre dans le tube peut jouer sur les résultats, suivant la nature du sol. Avec un sol sableux, les courbes (fig. 3) sont nettement distinctes suivant le degré de tassement. À la suite de nos résultats antérieurs (1962), nous avons donc tassé la terre dans les tubes chaque fois qu'il s'agissait de sols sableux. Ce tassement a permis d'amener la densité apparente au

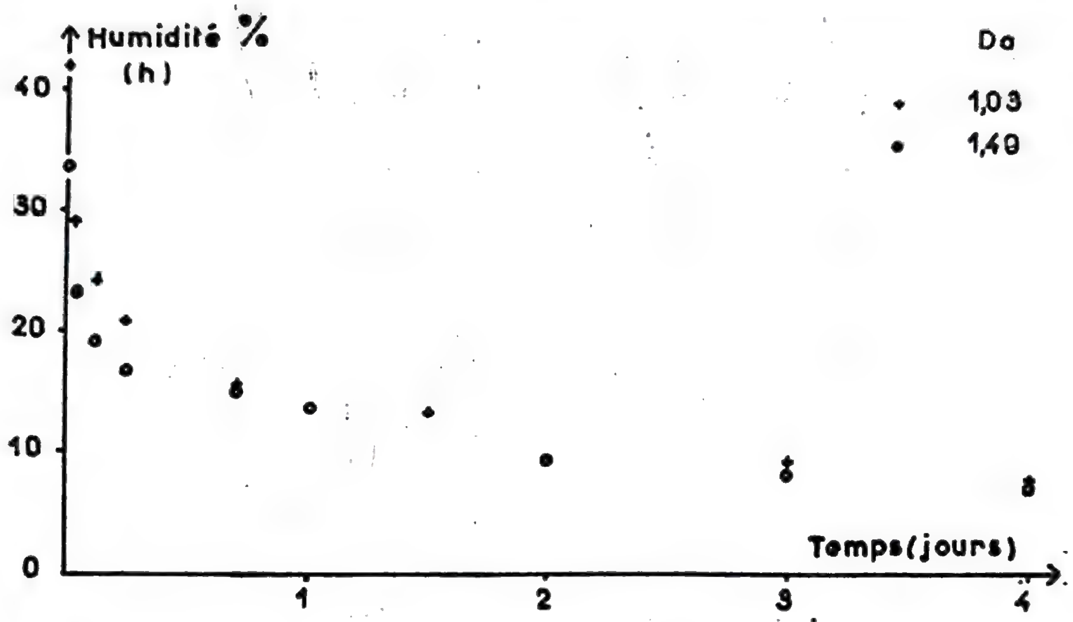

Fig. 3. Sol sableux. Influence du compactage : *Da*-densité apparente g/cm³.

voisinage de celle que le même sol a en place. Par contre avec les sols où la fraction colloïdale est notable, la nécessité de ce tassement n'est pas apparue à la suite d'un essai comparatif fait avec un sol limono-argileux moyennement gonflant (fig. 2).

3. *La distribution de l'humidité*, couche par couche à l'intérieur du tube ne montre pas de variations systématiques dès que le contact avec la terre sèche est établi.

III. RÉSULTATS ET DISCUSSION

La détermination des courbes de redistribution a été effectuée sur toute une série de sols. Nous avons choisi ces derniers aussi variés que possible, de façon à couvrir toute la gamme des compositions granulométriques. La plupart des sols étudiés proviennent de différentes régions de France, d'autres de la République Centrafricaine (Grimari).

Pour sept des sols étudiés, la capacité au champ a été mesurée en place par la méthode de Rode. Pour chacun des autres nous disposons d'un prélèvement d'humidité effectué à la sortie de l'hiver sur un sol apparamment ressuyé.

Les courbes $\Delta h/\Delta t = f(h')$ obtenues au laboratoire par la méthode indiquée peuvent être regroupées en quatre types principaux (fig. 4). Ce qui

caractérise l'ensemble de ces courbes c'est l'existence, dans les faibles humidités, d'une branche rectiligne AB, de très faible pente. Dans tous les cas cette branche a été définie par 4 points expérimentaux, au moins. Dans la gamme des humidités élevées on trouve également une branche rectiligne

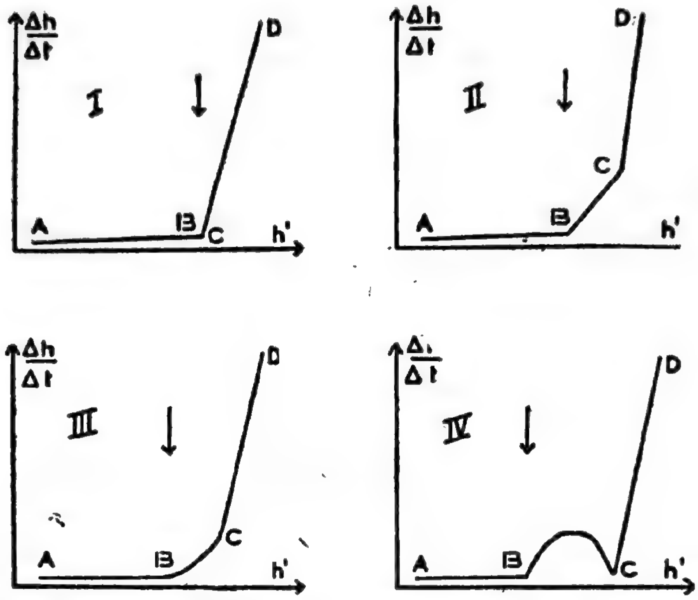

Fig. 4. Courbes types de rédistriution. La flèche indique la valeur de la capacité au champ.

CD. Cette branche n'est parfois définie que par deux ou trois points. Le point donné par le premier intervalle expérimental (entre $t = 0$ et le premier prélèvement) est quelquefois extérieur à la droite CD. Notons, à ce sujet, que l'humidité à $t = 0$ est mesurée dans le tube à l'issue de la préhumectation, mais avant qu'il soit mis au contact du support de terre sèche. Cette humidité n'est donc pas mesurée exactement dans les mêmes conditions que pour les temps qui suivent.

Entre les branches rectilignes AB et CD se trouve une zone intermédiaire où les points se repartissent différemment suivant les sols. Parfois, c'est un segment de droite (II), parfois une forme arrondie à concavité tournée vers le haut (III), parfois une courbe en cloche (IV). Quelques cas particuliers n'ont pas été portés sur les figures: la branche rectiligne CB peut être presque horizontale, et le raccordement avec AB marque alors une discontinuité. Ou bien dans cette zone intermédiaire les points se repartissent en nuage. Enfin, cette zone intermédiaire peut ne pas exister (I).

En portant sur ces graphiques la valeur de la capacité au champ mesurée en place, nous constatons que cette valeur se situe vers le point B, qui limite vers les humidités élevées la branche rectiligne des $\Delta h/\Delta t$ faibles. La concordance est très bonne, comme le montre le tableau 1.

On retrouve donc là le fait que la capacité au champ est l'humidité au-dessous de laquelle le drainage ou la redistribution sont relativement

Tableau 1

Comparaison des mesures effectuées sur différents sols

Texture du Sol	Appellation	En place: capacité au champ % de poids	Au laboratoire: Zone du point B humidité h' % de poids	Au laboratoire: $\Delta h/\Delta t$ (% heure) correspondant au point B	Au laboratoire: Forme de la branche *BC*
Sableux fin	Pierre Plate 15	16,6	16—17	0,5	II
Sableux fin	Pierre Plate 45	16,2	16	0,2	II
Sableux fin	KB 1 012 bis	10,6(1)	16	1,0	I
Sableux grossier	MB 1 041	13,3(1)	13—13,5	0,8	I
Sablo-argileux	LB 1 031	13,3(1)	14	0,2	I
Sablo-argileux	MC 1 041	15,3(1)	16	0,2	IV
Argilo-sableux	Grimari 0—15	21,1	21	0,5	IV
Argilo-sableux	Grimari 15—30	20,5	20	0,5	III à IV
Argilo-sableux	LB 1 041	19,4(1)	19	0,2	IV
Argilo-sableux	MB 1 013	24,8(1)	25	0,2	III
Limoneux	Closeaux 15—25	19,6	19—20	0,5	II
Limono-argileux	Closeaux 50	22,4	21—22	0,2	III à IV
Argileux	St Michel	38	40	0,4	II

(1) Mesures effectuées à une seule date.

lents. Ils ne sont cependant pas nuls, puisque le $\Delta h/\Delta t$ correspondant n'est pas nul. Il ne s'agit donc pas d'un arrêt complet de la circulation de l'eau, mais d'un ralentissement très notable. En d'autres termes il n'est pas exclu que ces courbes représentent la variation de la conductibilité en fonction de l'humidité.

Bien entendu cette méthode nouvelle pour la mesure de la capacité au champ peut comporter les limitations propres à toute méthode de laboratoire lorsqu'on travaille sur échantillons remaniés. En effet la structure d'une terre passée au tamis de 2 mm est parfois très différente de celle du sol en place. Ainsi un tassement plus ou moins prononcé des sols sableux joue sur l'exteusion vers la droite de la branche rectiligne *AB*. Cependant la bonne concordance entre la mesure au champ et celle au laboratoire observée pour les sols contenant de l'argile ou du limon semble indiquer que cette branche *AB* n'est pas affectée par l'état structural; on retrouverait là une caractéristique propre au matériau et donc probablement liée à la nature et à la repartition de ses pores les plus fins.

L'étude de l'allure des courbes de redistribution pourra certainement fournir ultérieurement des indications sur le comportement hydrique des sols. En effet la pente de la branche *AB* indique la variation de la vitesse de redistribution pour des humidités inférieures à la capacité au champ. De même la pente de la branche *CD* renseigne sur la variation de la vitesse de la circulation de l'eau dans la gamme des humidités voisines de la saturation. Enfin la zone intermédiaire *BC* correspond à des particularités du régime hydrique et certainement de la répartition de la porosité, dans la gamme des humidités situées immédiatement au dessus de la capacité

au champ. Pour les échantillons étudiés, nous avons rencontré le type III, qui correspond à un phénomène progressif, avec un sol argileux. Les types I et II, qui montrent un changement brusque dans la variation de $\Delta h/\Delta t$, sont les plus fréquents et se manifestent aussi bien avec des sables qu'avec des matériaux argileux ou limoneux. Enfin le type IV, qui indique un ralentissement puis une reprise du drainage, se présente avec des sols sablo-argileux ou argilo-sableux ; il n'est pas exclu qu'il soit dû à une porosité particulière liée à cette granulométrie discontinue.

IV. CONCLUSIONS

Connaissant la valeur de la capacité au champ mesurée en place par la méthode de Rode, notre méthode permet de retrouver cette valeur par une série de mesures extrêmement simples effectuées au laboratoire.

Les courbes $\Delta h/\Delta t$ montrent que la capacité au champ se situe à la limite de deux régimes différents dans la dynamique de l'eau. Ceci confère un sens physique à la grandeur étudiée.

L'étude des courbes $\Delta h/\Delta t$ pourra certainement fournir d'autres indications, encore inexplorées, sur le comportement hydrique des sols.

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RÉSUMÉ

Le principe de la méthode consiste à provoquer la redistribution de l'eau d'un petit échantillon de sol, initialement saturé, mis au contact du même sol sec. L'opération, répétée sur une série d'échantillons identiques, permet d'obtenir pour des temps différents la valeur correspondante de l'humidité (h'). À partir de ces valeurs expérimentales on calcule pour chaque

intervalle de temps la variation d'humidité $\Delta h/\Delta t$ qu'on reporte sur un graphique en fonction de l'humidité moyenne h' de l'intervalle considéré. La courbe $\Delta h/\Delta t = f(h')$ présente deux ou trois branches distinctes. Pour les plus faibles humidités d'un sol donné on observe une branche quasiment linéaire où $\Delta h/\Delta t$ varie peu.

Pour les sols étudiés, la valeur de la capacité au champ, provenant de mesures effectuées sur le terrain en période hivernale, se situe vers la valeur la plus élevée de h' de cette branche linéaire.

On décrit les conditions de réalisation des expériences, en précisant le rôle de quelques facteurs.

SUMMARY

The principle of the method is to induce the redistribution of water in an initially saturated soil sample put in contact with the same dry soil. The operation when repeated on an identical series of samples gives for different times the corresponding moisture values (h'). From these experimental values one calculates for each interval of time the variation of the moisture content $\Delta h/\Delta t$, which is plotted on a graph against the mean moisture content of the considered interval. The curve $\Delta h/\Delta t = f(h')$ shows two or three distinct branches. For the lowest moisture contents of a given soil, a quasi linear branch, where $\Delta h/\Delta t$ varies little, may be observed.

For the studied soils, the values of the field capacity, as provided by measures carried out in the field during the winter period, are situated toward the highest value of h' of the linear branch.

The experiment is described, and some experimental factors are discussed.

ZUSAMMENFASSUNG

Das Prinzip der Methode besteht darin, eine Wiederverteilung des Wassers einer ursprünglich gesättigten kleinen Bodenprobe hervorzurufen indem man sie mit demselben Boden in Berührung setzt. Das mit einer Serie gleicher Proben wiederholte Verfahren ermöglicht, für verschiedene Zeitpunkte den entsprechenden Feuchtigkeitswert zu ermitteln (h'). Von diesen Versuchswerten ausgehend, wird für jede Zwischenzeit die Feuchtigkeitsverschiebung $\Delta h/\Delta t$ ausgerechnet, die dann auf ein Schaubild im Verhältnis zur Durchschnittsfeuchtigkeit h' der jeweiligen Zeitspanne eingetragen wird. Die Kurve $\Delta h/\Delta t=f(h')$ zeigt zwei oder drei unterschiedene Abschnitte. Für die niedrigsten Feuchtigkeiten eines gegebenen Bodens ist ein beinahe linearer Abschnitt zu beobachten, wo $\Delta h/\Delta t$ sich wenig verändert.

Für die untersuchten Böden stellt sich der Feldkapazitätswert, welcher auf in der Winterperiode im Feld durchgeführten Messungen fusst, gegen den höchsten h'-Wert dieses linearen Abschnittes.

Es werden die Durchführungsbedingungen der Versuche dargestellt, wobei die Rolle einiger Faktoren präzisiert wird.

DISCUSSION

E. VETTERLEIN (Deutsche Demokratische Republik). Entsprechend der Inhaltsbestimmung des Begriffes „Feldkapazität" wie dieselbe zuerst von Veihmeyer durchgeführt wurde, ist die Feldkapazität als eine ökologische Grösse aufzufassen, in die auch der Wasserverbrauch durch die Vegetation eingeschlossen ist. Diese Auffassung des Begriffes „Feldkapazität" ist nicht mit derjenigen von Kossović und Tode identisch, welche die Feldkapazität mit der minimalen Wasserkapazität gleichsetzen. Unter natürlichen Bodenverhältnissen wird

der Wert der minimalen Wasserkapazität nur unter solchen Verhältnissen erreicht, in denen während längerer Zeiträume eine ungehemmte Absickerung des Gravitationswassers bei fehlender Wasserzufuhr vonstatten gehen kann. Die Höhe der Wasserspeicherung in natürlichen Böden ist jedoch auch deutlich von der Bodentemperatur abhängig und im Winter höher als im Sommer. Es wird daher jede Laboratoriumsmethode zur Bestimmung der Feldkapazität stets nur eine Annäherung an die natürlichen Verhältnisse ergeben können.

M. KUTILEK (Socialist Republic of Czechoslovakia). We suppose, that there are many other factors influencing the variation of the value of *FC* during the year. One of these factors is the soil water thixotropy.

A. FEODOROFF. Je suis tout à fait d'accord avec vous que les phénomènes thyxotropiques ont une influence dans le comportement des sols. Cependant, dans le cas considéré, les prélèvements en place ont été effectués dans des terrains à structure naturelle, relativement compacts, ce qui laisse à penser que les phénomènes thyxotropiques ne peuvent y avoir lieu. Néanmoins il est évident qu'au cours de l'humectation automnale la microstructure (porosité) est modifiée par le gonflement des argiles etc.

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I+VI. 1

PLANTS AS INDICATORS OF NEED FOR IRRIGATION

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The basic purpose of irrigation is to supply plants with water as needed to obtain optimum growth or optimum production of a desired plant constituent. Thus growth or production are the most important factors to be considered when determining irrigation need.

Numerous attempts have been made to find quantitative relationships between plant growth and soil water content or stress, or between plant growth and the atmospheric conditions which affect evapotranspiration. No useful relationships of general validity have been established, nor are such relationships to be expected (Kramer, 1959a, 1959b; Hagan and Vaadia, 1960a, 1960b; Slatyer, 1962, 1963; Vaadia et al., 1961).

It is being increasingly recognized that plant growth is related most directly to the water balance in plant tissues. As water deficits develop, physiological processes are disturbed, and growth and yield subsequently are affected. The relative rates of water absorption and water loss by plants determine their internal water balance which represents „the integrated interaction of plants with environment" (Mederski, 1961). These considerations have led Kramer (1963) to write: "In research dealing with plant water relations, the plant water stress itself should be measured as routinely as soil water stress or atmospheric factors... if the results are to be correctly interpreted".

Logically, evaluation of irrigation needs should be based on the growth pattern of crops as influenced by plant water stress or balance. Water should be supplied as needed so as to prevent any but minimum departures from the optimum growth curve. One approach to efficient irrigation is to measure plant growth and to apply water just prior to serious retardation in growth. Unfortunately, with most plants, by the time retardation in growth can be detected, some damage already has occurred which cannot be overcome by subsequent irrigations thus often resulting in loss of yield. A second and more fundamental approach is to correlate plant growth responses with the internal water balance, and seek to use such information as criteria for irrigation.

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However, the lack of adequate techniques for plant water measurement has handicapped research on relations between plant growth and internal water balance.

This paper calls attention to methods now available for measuring plant water status, and evaluates their usefulness under field conditions for scheduling irrigations. The use of plant growth, color, and other visual indicators of plant water stress also is discussed. The possibility of introducing selected or specially managed plants into cropped fields to serve as indicators of irrigation need is considered.

PLANT WATER RELATIONS AND MEASUREMENTS

The field of plant water relations has been reviewed extensively by Crafts et al., (1949), Veihmeyer and Hendrickson (1950), Richards and Wadleigh (1952), Veihmeyer, (1956), Hagan (1955), Hagan and Vaadia, (1960a, 1960b), Kramer, (1949, 1956, 1959a, 1959b, 1963), Russel (1959), Vaadia et al., (1961), Evenari, (1962), Slatyer, (1962, 1963), Gates (1964), and Kozlowski (1964). The tendency to use more basic physicochemical terminology has been given added impetus in recent years (Slatyer and Taylor, 1960; Taylor and Slatyer, 1961a, 1961b; Dainty, 1963; Slatyer, 1963; Lemon, 1963; Kramer, 1963) thus permitting more direct comparison of values for soil and plant water measurements.

Plant water status is most fundamentally described in terms of water potential. This potential, in a cell, is equivalent to the „osmotic potential reduced by the hydrostatic pressure induced by the elasticity of the cell wall or turgor pressure" (Slatyer, 1963). One expression for the plant water potential is the diffusion pressure deficit (*DPD*), also called suction force or suction pressure. It is a measure of the free energy of water in the plant cell (Meyer, 1945). This value expresses the energy state of water in the plant in a form parallel to that now increasingly used to report energy relations of water in soil and in atmosphere. Water potential is expressed in pressure units (atmosphere, bars, or dynes) or in energy units (ergs or joules per unit mass or volume). Conversions from pressure to energy units can be made, provided the specific volume of water and the temperature and pressure are known. The following unit conversions (Taylor and Slatyer, 1961b) are approximate (apply only to standard conditions and pure free water) (the symbol ($\approx$) indicates that units are numerically but not dimensionally equivalent):

Pressure units: 1 atm (STP) $= 1.013$ bars $= 1.013 \cdot 10^6$ dynes cm^{-2} ≈ 1033 cm water (equivalent length of supported water column).

Energy units: 0.1 joule gm^{-1} $= 10^6$ ergs gm^{-1} $\approx 10^6$ dynes cm^{-2} (1 bar) $\approx$ 1020 cm water.

A water deficit will induce changes in osmotic potential accompanied by similar changes in water potential. Thus, measurements of the osmotic pressure of the cell sap, and more recently of the water potential of the cells, are used to evaluate the water condition of the plant.

Kreeb (1963) claims that "*DPD* represents only the hydrature ('relative humidity', 'osmotic pressure') outside a cell, which must be considered responsible for the change of water from cell to cell. The 'osmotic value' of the cell solution represents the hydrature inside a cell, being in equilibrium with the hydrature of the protoplasm (its imbibition) where life processes such as growth, respiration and photosynthesis are taking place." Thus Kreeb believes that the osmotic value of the cell sap is thereby a better indicator of the plant internal water balance than is the plant water potential.

However, it can be argued that osmotic pressure measurements made on expressed sap under atmospheric pressure neglect the turgor pressure component of the plant water potential. Thus, as implied by Kramer (1959 a, 1959 b, 1963) and Slatyer (1962, 1963), plant water potential appears to be a better representation of internal water balance in plant tissues for the following reasons. Water potential is a measure of the energy level or chemical potential of water under conditions actually prevailing within cells in undisturbed tissues. It is also a measure of the pressure with which tissues can absorb water when placed in pure water (Kramer, 1959 a). It is generally assumed that the energy level of water in plants largely controls the rate and extent of many physiological and metabolic phenomena, e.g., cell turgidity, cell elongation, cell division, hydration of protoplasm, enzymatic reactions, and absorption and translocation of water and solutes.

The difficulties in measuring plant water potential with sufficient precision have led investigators to be satisfied with other parameters less fundamentally related to the internal water status of plants. These include water content of plant parts, osmotic potential of the cell sap, or processes affected by water potential, such as stomatal opening in leaves and hence transpiration rate. The following section briefly summarizes the various methods used for the measurement of the internal water balance of plants. More information is available in Crafts et al. (1949), Eckardt (1960), and Slatyer and McIlroy (1961). A detailed review is being prepared by the present authors.

1. *Measurement of Internal Water Balance*

a) *Water Content*

One expression is the absolute water content (reported as percent water per unit fresh or dry weight). This is generally unsatisfactory because fresh weight and dry weight vary both diurnally and seasonally. A second expression is the relative water content defined by Weatherley (1950) as "relative turgidity" (fresh weight minus dry weight over turgid weight minus dry weight) and by Stocker (1928) as "water saturation deficit" (turgid weight minus fresh weight over turgid weight minus dry weight). A full discussion of measurement methods and evaluation of techniques are given by Barrs and Weatherley (1962), Catsky (1963), Jarvis and Jarvis (1963a), and Slatyer and Barrs (1965).

Relative water content is a more reliable expression of the internal water balance of plants than absolute water content because of the large variability of the latter. Correlations between relative water content and plant water potential have been reported for various plant species: tomato *(Lycopersicum esculentum)* and privet *(Ligustrum lucidum)* (Weatherley and Slatyer, 1957; acacia *(Acacia aneura)* (Slatyer, 1958); eucalyptus *(Eucalyptus globulus)* (Carr and Gaff, 1961); lupine *(Lupinus albus)* (Jarvis and Jarvis, 1963a); aspen *(Populus tremula)*, birch *(Betula verrucosa)*, pine *(Pinus sylvestris)*, and spruce *(Picea abies)* (Jarvis and Jarvis, 1963b); pepper *(Capsicum frutescens)*, cotton *(Gossypium hirsutum)*, birds-foot trefoil *(Lotus corniculatus)* (Ehlig, 1962).

Unpublished data exist for several other plants: sunflower *(Helianthus annuus)* (Vaadia et al. [1]) and alfalfa *(Medicago sativa)*, bluegrass *(Poa pratensis)*, curled dock *(Rumex patientia)*, dandelion *(Taraxacum sp.)*, soybean *(Glycine soya)*, juniper *(Juniperus sp.)*, maple *(Acer saccharum)* and pine *(Pinus strobus)* (Gavande and Taylor [2]). These correlations have shown some constancy within species over a wide range of conditions (Jarvis and Jarvis, 1963b).

The beta ray gauging technique was developed to measure (and record) changes in absolute leaf water content (Mederski, 1961). Correlations have been established with both relative leaf water content and water potential (Whiteman and Wilson, 1963; Nakayama and Ehrler, 1964; Gardner and Nieman, 1964). This non destructive method shows promise for use in field determination of water needs for crops.

b) *Xylem Tension*

Electrical conductance was used as a nondestructive method for measuring xylem tension in herbaceous plants (Box and Lemon, 1958; Namken and Lemon, 1960) and in almond *(Amygdalus communis)* trees (Henderson[3]). Henderson developed, for use in trees, an electrode, which is quite sensitive to rapid diurnal variations in xylem tension presumably reflecting corresponding changes in water potential.

c) *Osmotic Potential*

Methods for measuring plant osmotic potential have been extensively reviewed (Miller, 1938; Crafts et al., 1949; Bennet-Clark, 1959). The most valuable methods are the cryoscopic technique (Walter, 1931; Crafts et al., 1949; Kreeb, 1961) and methods applicable to the measurement of water

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[1] Vaadia, Y., Hagan, Robert M., and Raney, F. C. Unpublished research from University of California report to (U.S.) Regional Research Project W- 67 (October 1960).

[2] Gavande, S. A., and Taylor, S. A. Unpublished research from Utah State University report entitled „Measurement of Energy Status of Water in Soil-Plant-Atmosphere System" to (U.S.) Regional Research Project W-67 (October 1963).

[3] Henderson, D.W., Personal communication (1964).

potential (see next section). The later methods require prior freezing of the tissue to disrupt cell membranes and eliminate the turgor potential component. For field studies a method using a refractometer has been described by Lemée and Laisné (1951).

d) *Water Potential*

Direct methods now used fall into two classes: the equilibration (liquid or vapor) and the psychrometric techniques. In equilibration techniques, samples of plant tissue are permitted to come to equilibrium either with solutions of known osmotic potentials or with vapor above such solutions (Ursprung and Blum, 1916; Slatyer, 1958). In the equilibration process, a solution is selected which produces no change in weight, length, or volume of tissue (Slatyer, 1958) or which shows no change in density after contact with the tissue (Schardakov, 1956). The osmotic potential of the selected equilibrium solution then equals the water potential of the tissue being tested. The Schardakov or dye method (Schardakov, 1953, 1956) can be employed for the field determination of plant water potentials, but erroneous results have been reported for pine and citrus (Gale[1]). It does not depend on elaborate instrumentation or temperature control required by the other techniques.

In psychrometric techniques, the relative water vapor pressure surrounding a plant sample is computed from thermocouple measurements (Richards and Ogata, 1958; Monteith and Owen, 1958; Ehlig, 1962). Temperature control within approximately $\pm$ 0.001°C is an absolute requirement of this method.

2. *Measurements of Transpiration and Stomatal Aperture*

a) *Transpiration Rate*

Transpiration measurements have not been used extensively for scheduling irrigations, partly because of difficulties in measurement. Methods of measurement are reviewed by Kramer (1959 a). The thermoelectric method (Huber and Schmidt, 1937) was used by Bloodworth et al. (1955, 1963) for measurement of sap velocity in herbaceous plants and by Ladefoged (1963) and Decker and Skau (1964) for forest trees.

b) *Stomatal Aperture*

Stomatal aperture is considered a sensitive indicator of internal water deficits (Stalfelt, 1955; Kramer, 1959 b ; Evenari, 1962).

Practical measurement methods include: (1) Infiltration technique in which the rate and extent of diffusion of various liquids applied to the stomatous side of a leaf are used to indicate the extent of stomatal aperture (Molisch, 1912; Oppenheimer and Elze, 1941; Alvim and Havis, 1954; Ophir and

[1] Gale, J. Personal communication to authors (1964).

Putter, 1959) and (2) porometers which measure the rate of gaseous diffusion through a leaf surface. Porometers suitable for field use were developed recently (Alvim, 1963 and Bierhuizen et al., 1965).

Microscopic measurement of stomatal aperture may be done by means of a stomate camera (Williams et al., 1961) or by several imprint techniques, e.g., silicone rubber impression method (Zelitch, 1961).

IRRIGATION SCHEDULING BY USE OF PLANT WATER MEASUREMENTS

Ecological studies of plant associations under arid and semiarid environmental conditions have stimulated much continued interest in evaluating the water balance of plants. Many aspects of the plant water balance have been measured simultaneously; these include relative water content, stomatal opening, transpiration rate, and osmotic and water potentials. Reviews are available in UNESCO Arid Zone Research Symposia (1960, 1961, 1962).

Agricultural scientists have attempted to develop simple methods which will provide the farmer with a usable criterion for scheduling irrigations. Research dealing with physiological indicators of water need has been confined mainly to countries containing areas characterized as arid or semiarid (see Petinov, 1961). Space permits a review of only the more recent work on the use of indicators in relation to their usefulness for scheduling irrigations.

1. *Water Content*

Extensive use of absolute water content as the criterion for irrigation has been reported only by the sugar cane *(Saccharum officinarum)* industry (Clements and Kubota, 1942; Clements et al., 1952; Tanimoto, 1961; Chang et al., 1963). The principal difficulty in this approach is selection of a plant part with a water content quite sensitive to water stress, but yet little influenced by fertilization and other environmental variables. Despite many studies seeking to use plant water content for scheduling irrigations, most of the sugar cane industry still relies upon soil water measurements, partly because of convenience and better calibration.

Relative water content was found useful in many ecological studies as an indicator of the internal water balance of plants. But it has, to our knowledge, seldom been used for scheduling irrigations.

Rutter and Sands (1958) working with pine leaves, estimated that leaf water deficit, if measured at sunrise, appears to be the best plant index of soil water stress adjacent to roots. Halevy (1960a, 1960b) made a comprehensive study of the variations in daily transpiration, leaf water content, stomatal aperture, water saturation deficit, osmotic values, and leaf elongation of gladiolus, as soil water stress progressively increased. Although Halevy considers water saturation deficit to be the most sensitive plant factor, he belie-

ves that stomatal aperture measurements were nearly as sensitive and are easier to make.

Determinations of relative water content should be useful to indicate irrigation need because of (1) simplicity of sampling and measurement and (2) generally good correlations with plant water potential and presumably with growth. Further studies of such correlations should be encouraged.

2. *Xylem Tension*

Soil water tensions have been measured extensively by an electrical conductance method using small porous blocks introduced by Bouyoucos and Mick (1940). This method has been adapted for the measurement of xylem tensions in trees only recently (Henderson [1]). These measurements are expected to correlate closely with plant growth responses. No recommendations can yet be made for use of this method to schedule irrigations.

3. *Osmotic Potential*

Walter (1955) claims that the cell osmotic potential is an indicator of the plant's "hydrature" (or plant water balance). The osmotic potential of plants varies considerably with plant species, time of year, and environmental conditions, such as fertility and salinity of the soil. Despite these shortcomings, the ease with which osmotic potential can be determined has led to its use as an indicator of water need for many years (Miller, 1938, to Kreeb, 1963).

Lobov (1951, 1957) reports field experiments in which cabbages, potatoes and tomatoes were irrigated only when the plants reached a maximum osmotic potential of 8, 10 and 12 atmospheres, respectively. A decrease in yield generally was associated with a rise in plant osmotic potential.

Bauman (1955), as cited by Kreeb (1963), scheduled irrigations of alfalfa *(Medicago sativa)*, wheat *(Triticum)*, barley *(Hordeum)*, oats *(Avena)*, sugar beets *(Beta saccharifera)*, and potatoes *(Solanum tuberosum)* on the basis of osmotic potential determined cryoscopically on expressed leaf cell sap. He found a significant negative correlation between "average *OP*" and yield; the higher the "average *OP*", the lower the total yield.

Cell sap concentration (as per cent total solids or refractive index value of cell sap) was evaluated as an irrigation criterion by Schmueli (1953) on bananas *(Musa)*, Kreeb (1958) and Slavik (1959a, 1959b, 1959c) on barley, Ophir and Putter (1959) and Filippov (1959a, 1959b) on cotton, Belik (1960) on tomatoes, Belik (1962) on cucumber, Filippov (1961) on nine apple *(Malus spp.)* varieties, Halevy (1960a, 1960b) on gladiolus, Rodionov (1962) on corn *(Zea mays)*, Babushkin (1959) on tomatoes and potatoes *(Solanum tuberosum)*; Chunosova (1963) on sugar beets, and Davis (1963) on canteloups *(Cucumis melo cantalupensis)*. These authors describe methods of measurement used. In many

[1] Henderson, D.W. Personal communication (1964).

instances, they also give specific recommendations on time and procedure for sampling and on scheduling irrigation from *OP* measurements for example, Filippov (1959 a), following Lobov (1949, 1951), found the cell sap concentration of cotton leaves (as measured with a field refractometer) to vary 2 per cent to 3 per cent diurnally and to range from 11—12 per cent in wet soil to 22—23 per cent in dry soil. A concentration of 15 per cent was usually accompanied by wilting. His calculations indicated that the correlation factor between leaf sap concentration and leaf water potential varied from 0.74 to 0.85. He recommended that cell sap concentration values be held below 12 per cent for optimum growth.

It should be pointed out that some of these investigators may have made measurements which also reflect total water potential; however, in some instances this cannot be determined from the published descriptions of methods used. Also lacking in many papers is a precise description of environmental conditions prevailing during the experiments. As outlined previously, such information is vital to the use of osmotic potential as a reliable indicator of water need.

4. *Water Potential*

The lack of a method for determination of water potential which is truely adaptable to field use has delayed its employment as an indicator of water need. The apparent reliability and simplicity of the Schardakov method suggest its use on a broader basis. It has been recommended for scheduling the irrigation of cotton by Schardakov (1938, 1956), Filippov (1954 a, 1954 b, 1959 b), Neshina (1955) and Krapivina (1963); of alfalfa by Kolesnikova (1957); and of wheat by Petinov (1959).

Filippov (1959 b) states that growth of cotton is checked when the plant water potential reaches 14 atmospheres. Krapivina (1963) gives specific recommendations which depend on the stage of growth of the plants. By using measurements of plant water potential, Krapivina was able to reduce the number of irrigations and total water applied without affecting the yield of cotton.

Space does not permit discussion of plant water potential determinations made by ecologists in their studies of the water balance of plant communities. It should be noted, however, that Evenari (1961, 1962) considers the plant water potential (determined by the Shardakov method) as one of the best indicators of water need. With additional research relating plant growth to water potential, it is likely that plant water potential measurements will become more widely used for irrigation scheduling.

5. *Transpiration*

Although transpiration measurements are quite common in ecophysiological studies, they have not been found useful for scheduling irrigations. Instead stomatal aperture determinations, which are only indirectly related to transpiration, are preferred as being more practical and easy to use.

6. *Stomatal Aperture*

Maximov and Zernova (1936) concluded that stomatal aperture was valuable for scheduling irrigation of wheat. Oppenheimer and Mendel (1939) and Oppenheimer and Elze (1941) used infiltration techniques on citrus leaves as indicators of water need. This test, reported to be quite simple and sensitive, was recommended except under conditions of either very high or very low relative humidities. It must be recognized that the stomatal aperture of leaves on any given plant will be influenced by age of leaves and exposure to light and wind.

Shmueli (1953) concluded that stomatal aperture of banana leaves directly exposed to sunlight when measured at midday provides a reliable indication of soil water deficits. A marked depression in aperture was exhibited by stomates of plants in soil at 2/3 field capacity as compared to that in plants at field capacity. Rutter and Sands (1958), Sands and Rutter, (1959) found that both the total number of open stomates in pine and the time they remain open are reduced by an increase in soil water tension.

For scheduling the irrigation of cotton and corn, Ophir and Putter (1959) applied the infiltration method using a 1:2 mixture (by volume) of paraffin and turpentine. Halevy (1960 a, 1960 b) reported the use of stomatal aperture measurements (made 3 hours after sunrise) as the basis for irrigating gladiolus.

IRRIGATION SCHEDULING BY USE OF PLANT GROWTH AND INDICATORS OF WATER STRESS

Pending further developments in measurement of plant water stress and in our understanding of its relation to plant growth, greater attention should be given to possibilities for improving methods involving indicators of plant water stress as criteria for irrigation needs. These methods include growth measurements of certain plant organs; leaf angle, color, reflectance and temperature; exudation from a cut plant; and the use of selected or specially managed plants in cropped fields. Some of these methods should be particularly valuable for improving irrigation scheduling in areas which do not possess the instruments or personnel necessary for soil and plant water measurements.

1. *Growth Indices*

Since water deficits affect plant growth, why not use measurements of growth as an indicator of water need? This idea is not new. Early in this century, investigators made numerous observations on the effects of water deficits on growth (Maximov, 1929). When improved methods permitted measurements of soil water content and stress, interest declined in the use of growth measurements as the basis for irrigation. Realizing that favorable

plant growth is the ultimate aim of irrigation, and recognizing the limitations of soil water measurements for scheduling irrigations, it seems desirable to re-examine the usefulness of fruit, leaf, or stem growth as irrigation criteria.

There are many problems involved in using growth as a criterion, for growth is a slow complex process strongly affected by environmental factors in addition to water. Each plant species, and even individual plants and organs, have their own growth patterns. It is critical not only to select a plant organ particularly responsive to water stress, but also to establish, for reference, a growth curve for that organ under the conditions most conducive to optimum growth. Determination of this growth curve requires extensive investigation.

Visual observations of growth may be useful in some instances as with cotton (Stockton, 1961). See discussion below. Growth should become a more reliable indicator of water need where sensitive growth measuring devices, such as dendrometers, are developed. Some require careful installation and calibration. These devices may be invaluable for research use, but some may be too delicate or their use too tedious for commercial irrigation scheduling.

a) *Fruit growth*

Magness, Degman and Furr (1935) suggested the use of fruit growth as a guide to irrigation of apples. Furr and Taylor (1938) demonstrated a positive correlation between enlargement of lemon *(Citrus lemon)* fruits and availability of soil water. Oppenheimer and Elze (1937, 1941) recommended irrigation of orange *(Citrus sinensis spp.)* trees whenever, during the summer, the daily increment in fruit circumference falls below 0.2 to 0.3 mm (equivalent to an increase in fruit volume of 2 ml per day). They recommend using fruit growth as the indicator of water need from July to November and using stomatal infiltration during the rest of the year. Ladin (1959) studied both fruit and trunk growth of apple trees subjected to several different irrigation treatments. Rate of fruit growth decreased gradually as water was extracted from the soil. This relation also was observed by Uriu et al. (1964) in their extensive experiments with peaches *(Prunus persica)* and prunes (*Prunus domestica*).

Techniques for measuring fruit growth generally have been simple and have lacked precision. Most authors used a tape or a caliper. Dietz and Verner (1942) continuously recorded potato tuber enlargement by means of an auxanometer. This apparatus, also called auxograph or auxometer, was used by Bartholomew (1926) to measure daily cycles in the expansion and contraction of well-developed lemon fruits. Later, Anderson and Kerr (1943) used it to study growth behaviour of cotton bolls and elongation of stems and leaves. Tuckey (1963) adapted a linear displacement voltage transducer for continuously recording the rate of fruit enlargement. He used this promising new tool for measuring fruit growth of cucumbers (*Cucumis sativus*), apples, and tomatoes over a range of environmental conditions.

b) *Leaf growth*

Leaf growth involves changes in length, area or thickness (Milthorpe, 1956). The first two parameters are undesirably dependent on many environmental factors besides water, including fertilization. A new form of contact auxanometer suitable for recording leaf elongation was developed by Idle (1955, 1956).

Another sensitive apparatus for measuring changes in leaf thickness was devised by Meidner (1952) who showed that leaf thickness changes quickly with variations in leaf water content induced by transpiration. He found no correlation between leaf thickness and soil water tension. The beta ray gauging technique (Mederski, 1961; Nakayama and Ehrler, 1964; Whiteman and Wilson, 1963) yields a value integrating both leaf thickness and water content. Relations between changes in thickness and relative turgidity of leaves have been evaluated for sugar beets and beans (Gale, 1962). However, it may be possible to schedule irrigations from leaf thickness measurements in crops, such as pineapple *(Ananas sativus)*, having leaves which are measurably affected by water stress.

c) *Stem and Trunk growth*

Measurements of stem growth, as well as of leaf growth, have been made usually only to evaluate the effects of environmental changes on the plant. Stem growth is affected decidedly by water stresses, as demonstrated by: Gates (1955) on tomatoes, and Owen (1958a, 1958b) on sugar beets, Vaadia and Kasimatis (1961) on grapes, Clements and Kubota (1942), Clements et al., (1952) and others on sugar cane, Stockton et al. (1961), Marani and Horwitz (1963) on cotton, and Uriu et al. (1964) on peaches. Some recent studies of stem growth patterns are available which could provide the basis for using stem growth as an indicator of water need.

An 80 per cent correlation between sugar cane stalk length and final yield of sugar was reported by Desornay and Davidson (1959). They concluded that a maximum rate of stalk elongation should be maintained throughout the growth of sugar cane plants for maximum sugar yields. Stalk elongation was also shown to decrease with increasing soil water tensions (Mallick and Venkataraman, 1957; Leverington, 1960; Cornelison and Humbert, 1960; Robinson, 1963; and Robinson et al., 1963) and to be greatly reduced by soil water tensions higher than 2 bars (Robinson, 1963). These studies suggest that stalk elongation measurements are useful indicators of critical soil water levels (Robinson et al., 1963) and thus may be used for irrigation scheduling.

The effects of water stress on plant height are summarized by Kozlowski (1964). A low soil water supply interferes with growth of the younger parts of some plants causing shorter internodal spacing. This has been observed in corn by Miller and Duley (1925) and Howe and Rhoades (1955). Stockton et al. (1955) and Stockton and Doneen (1957), Stockton et al. (1961) have used successfully observations of internodal spacing below the growing tip to schedule irrigation of cotton. They report that yields are not reduced by delaying irrigation until the internodal spacing is noticeably shortened. Vaadia

and Kasimatis (1961) have suggested that elongation of the growing tips of grape *(Vitis spp.)* vines may be useful in planning irrigations. Widespread use of stem elongation as an indicator of water need awaits more detailed studies and probably the development of a sensitive, yet easily used, measuring device. The auxometer adapted by Wilson (1948) for measuring stem elongation still appears to be the most sensitive device available.

Measurements of radial growth of trees are made routinely in forest management studies. Dendrometers, instruments which can be used to measure both radial growth and diurnal shrinkage, have been employed frequently (Reinecke, 1932; McDougal, 1936; Daubenmire, 1945). Introduction of a high-precision model (Verner, 1962a) has led to extensive experimentation with fruit trees to determine the usefulness of dendrometers for scheduling orchard irrigation (Verner, 1962b; Verner et al., 1962; Hagan and Martin[1]). Measurements of growth rates and diurnal shrinkage are compared against corresponding values for trees well supplied with water. Whenever growth rates decline below the check, or diurnal shrinkage exceeds the check, the need for irrigation is suggested (Hagan and Martin[1]). Dendrometers appear to be useful in research on the water balance of trees. Their suitability for irrigation scheduling under practical farming conditions should be given further study.

2. *Visual Indicators of Water Stress*

Wilting is the most common visible sign of moisture stress. However, it frequently has been demonstrated that growth of plants generally is affected by water stress before wilting is apparent.

Thus there is a need for visual indicators which may warn of water stress before growth is checked. There are several possibilities, including plant movements affected by turgor changes, plant color, and leaf reflectance. The extent to which such changes may be visible prior to a check in growth is considered below.

a) *Plant movements*

Pronounced diurnal movement of leaves has been known and repeatedly observed in many plants (Darwin and Darwin, 1880; Daubenmire, 1948; Meyer and Anderson, 1952; Stern, 1962) notably in the *Oxalidaceae*, the *Leguminoseae* and the *Gramineae*. Grasses such as bluegrass (*Poa spp.*), etc. exhibit an involute curling of the upper leaves during the day, probably because of temporary water deficiency. This reduces direct radiation received per unit area and shades part of the leaf surface. The leaflets of many legumes fold upward together in such a manner that approximately half the leaf surface is protected. Turgor movements are responsible for these changes in shape (Meyer and Anderson, 1952). Careful studies of these movements under increasing

[1] Hagan, Robert M. and Martin, Paul E. Unpublished research from University of California report to (U.S.) Regional Research Project W-67 (October 1963).

water deficits may lead to useful indicators of water need. Changes in leaf angle in sorghum have been used successfully for scheduling irrigation (Henderson [1]). Use of this criterion permitted a significant saving in water without decreasing yield. Beans (*Phaseolus spp.*) display a noticeable change in leaf angle as water stress increases. This has provided a useful irrigation guide in western United States.

b) *Plant color*

In many plants, color of foliage is affected by water stress. Leaves of beans, cotton peanuts *(Arachis hypogea)* and many other plants become dark green under water deficits. Burman and Painter (1964) observed the change in color of small new leaves of beans grown under greenhouse conditions. They reported that the character of the color change caused by soil-water stress differed for various stages of growth and was most distinct in the seedling stage. Doneen and Henderson[2] have noted that the color change produced by water stress depends on whether the plants are grown under greenhouse or field conditions. For field grown beans, a change in leaf color from light to dark green is reported by Howe and Rhoades (1961) to be a useful guide to the proper time for irrigation. In their work, this change usually occured when the soil water content of the top foot reduced to one-half that at field capacity. With some varieties of beans, increasing water stress alters the leaf angle which changes the apparent color of the crop by exposing more of the lighter undersurface of leaves. Water-stressed crops may appear lighter or yellower in color thus providing a suitable criterion for irrigation.

Reddish or brownish coloration develops in some plants sujected to water stress. Well-watered cotton often has 3 to 4 inches of tender, green stem between the terminal bud and the reddish part of the stalk. A decrease in this distance indicates checking of growth and a need for water (Hoover and Booher, 1952).

Bildro et al. (1960) irrigated cotton according to change in leaf color. They observed periodically the newest leaf at the top of the plants. Water was applied when the leaf color darkened.

Under their conditions, this approach led to higher yield, but increased water consumption. They concluded that this method could not yet be recommended.

3. *Other Indicators of Water Stress*

These include leaf reflectance and temperature and exudation from a cut plant.

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[1] Henderson, D. W. Unpublished research from University of California W-29 report 1955.
[2] Doneen, L. D. and Henderson, D. W. Personal communication.

a) *Leaf reflectance*

A clean, disease-free leaf with very turgid spongy mesophyll tissue is highly reflective of infrared light. Decreased turgidity of leaf causes collapse of the mesophyll cells, resulting in a loss of infrared reflectance (Colwell, 1956). Infrared reflectance decreases before any change in reflectance occurs in the visible part of the spectrum. By infrared aerial photography, it has been possible to detect areas in cropped fields affected by disease or salinity (Colwell, 1956, 1961 : Myers et al., 1962 ; Marcus, 1963). Beginning about 7 years ago in California, a commercial infrared aerial photography service was offered for several seasons to farmers to guide them in scheduling irrigations, particularly for orchards.

Stanhill[1] proposes that infrared reflectance be scored visually, colorimetrically, or photoelectrically. He suggests developing a simple but sensitive photocell with suitable filters. Its readings then could be correlated with soil and plant moisture data from plants subjected to various irrigation treatments. The qualities of a good photocell are evaluated by Stern (1962).

b) *Leaf temperature*

Leaf temperature, measured by an infrared thermometer, may be a valuable qualitative index to differences in plant water regimes, and may serve to provide quantitative data on plant water stress (Tanner, 1963). Further work on this approach is needed.

c) *Biochemical changes*

It is well known that internal water deficits affect substantially the metabolism of plants (for reviews see Stocker, 1960 ; Petinov 1961 ; Vaadia et al., 1961 ; Kozlowski, 1964). The normal pattern of biochemical reactions is altered both qualitatively and quantitatively, generally long before growth is noticeably retarded. Thus, it is important to know and be able to detect measurably those reactions most affected by internal water deficits. For example, given water stress levels may cause the accumulation or depletion of certain enzymes or other constituents. Measurements of plant constituents, therefore, could provide an indicator of internal water balance. If simple tests for detecting such changes can be developed, they may become useful for irrigation scheduling.

d) *Exudation*

Exudation from detopped plants depends directly on root pressure which has been reported to be depressed at soil water contents above the wilting point (Kozlowski, 1964). Thus exudation will generally cease when

[1] Stanhill, G. Personal communication to authors (1963).

the available soil water is only partially depleted. Since the original observations by Litvinov and Gebhardt (1929) on several detopped plants, exudation has been studied on coleu, tomato, and sunflower (Kramer, 1941) ; sunflowers (McDermott, 1945; Hagan, 1949; and Vaadia, 1960) ; beans, corn, tobacco *(Nicotiana spp.)* and tomato on various soils (Army and Kozlowski, 1951) ; and cotton (Filippov, 1954a and 1956). These investigators have sought to determine the soil water content or tension at which exudation ceases. Filippov is reported (Petinov, 1961) to recommend irrigation of cotton before exudation from detopped plants ceases permanently. This approach deserves further investigation, for it may prove to be one of the simplest methods for determining irrigation need.

4. *Selection and management of plants as indicators for irrigation*

For scheduling irrigation, the farmer needs a simple, inexpensive, and yet reliable way to warn him of water depletion before the crop is affected. An old but still promising idea is to grow, alongside the crop, indicator plants which will exhibit visual symptoms of water stress earlier than will the crop plants. These indicators could be plants which are naturally more susceptible to water deficits than are the crop plants, or they could be plants selected from the crop to serve as indicators, and so managed that they will exhibit water stress symptoms earlier than the normally managed crop plants.

a) *Selection of indicator plants*

This selection will require considerable experimentation to ascertain the comparative responses of plant species and varieties to increasing soil water stress. Studies made on drought tolerance and resistance should be examined for this purpose. The most promising approach would appear to involve the selection of indicator plants having a top to root ratio exceeding that for the main crop. Plants with shallow and/or sparse roots are more sensitive to water deficits than plants with deep and/or well-branched roots. They may therefore be used successfully as indicators in a crop having deeper and/or denser roots. Also some plants with a higher transpiration rate or less xerophytic characteristics than the crop may exhibit transient wilting early and thus indicate water need. Some limitations, other than susceptibility to water deficit, must be considered in selecting indicator plants. Such plants should not interfere with cultural operations, nor should they constitute potential weed hazards or hosts for crop pests.

b) *Management practices*

It may no tbe possible to find for all crops and conditions another species or variety which will exhibit signs of water stress before the crop plants are affected. Plants selected from the crop to serve as indicators could be made

more sensitive to soil water depletion by application of growth regulators to increase the toproot ratio, or by retarding or limiting root growth through cutting roots, compacting soil around roots, or confining roots with mechanical barriers. Plants to be used as indicators may be planted later than the crop or placed in soil mixed with sand to reduce its content of available soil water. To determine need for irrigation, experienced agriculturalists have long used the appearance of crop plants growing on sandy, shallow or compacted areas in fields. Plants for indicators could be planted at closer spacing to increase water use rates and thus hasten appearance of water stress symptoms. Although these approaches are qualitative and will require considerable experimentation and local adaptation, they may be useful in the absence of more refined methods for scheduling irrigations.

CONCLUSIONS

The wide variety of measurements, techniques and observations now available for using the plant to indicate water deficits may be confusing to scientists studying plant water relations and even more confusing to agronomists seeking a sensitive indicator for irrigation scheduling. To be useful for this purpose, plant indicators should: (1) warn of water need early enough to permit irrigation before the crop is adversely affected; (2) provide reliable and consistent information on water deficits; and (3) be simple to use and preferably inexpensive.

While this paper has dealt with the scheduling of irrigations, it must be recognized that optimum scheduling is only one of the requirements for efficient irrigation. The second requirement, for efficient use of water, is to apply at each irrigation a depth of water equal to the evapotranspiration losses plus allowances for leaching where necessary. Soil water sampling, calibrated tensiometers or blocks, or computations from evapotranspiration data are still needed for the exact determination of the soil water deficit.

In conclusion, plant indicators (for need to irrigate), together with information on soil water deficits or cumulative evapotranspiration (for depth of water to apply) provide the basis for efficient irrigation and favorable crop yield. Under certain known conditions, plants may eventually be used to indicate both the need for and the amount of irrigation water. This, obviously, requires that it has been possible to establish correlations between plant water stress and soil water deficits, such correlations being at best only approximate and applicable under specific cropping and environmental conditions.

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SUMMARY

Many investigations have sought to establish criteria of need for irrigation based on measurements of soil water or atmospheric conditions. However, no relationships of universal applicability can be established between plant growth and these measurements. Since plant processes are determined directly by water conditions within the plant, irrigation criteria based on plant water should be less influenced by local conditions and should have nearly universal application.

Approaches to studying plant water balance are summarized and their usefulness evaluated for irrigation research and programming. These include measurements of tissue water content, growth rate, stomatal opening, and cell sap concentration. Also considered are leaf color or other visual indicators of plant water stress and the use of selected or especially managed plants introduced into crop fields.

RÉSUMÉ

De nombreux chercheurs ont essayé d'établir des criteriums sur la nécessité de l'irrigation, basés sur les mesurages de l'eau du sol cu des conditions atmosphériques. Toutefois, on ne peut pas établir des relations générales entre la croissance de la plante et ces mesurages. Parce que les

processus des plantes sont déterminés directement par les conditions hydrologiques à l'intérieur de la plante, les critériums pour l'irrigation basés sur l'eau de la plante doivent être moins influencés par les conditions locales et avoir presque une application universelle.

Des essais pour étudier le bilan d'eau de la plante sont synthétisés et leur utilité évaluée pour les recherches et le programme de l'irrigation. Ceux-ci comprennent des mesurages de la teneur en eau des tissus, du rythme de croissance, de l'ouverture des stomates et de la concentration de la sève de la cellule. De même, on a pris en considération la couleur des feuilles ou d'autres indicateurs visuels de la tension de l'eau de la plante et l'introduction dans les champs cultivés des plantes sélectionnées ou cultivées de façon spéciale.

ZUSAMMENFASSUNG

Zahlreiche Forscher haben daran gedacht, Kriterien für den Bewässerungsbedarf festzulegen, die sich auf Messungen des Bodenwassers oder der Witterungsverhältnisse gründeten. Dennoch können keine Beziehungen mit allgemeingültiger Anwendbarkeit zwischen Pflanzenwachstum und diesen Messungen festgelegt werden. Da die Entwicklungsprozesse der Pflanze unmittelbar durch die Wasserverhältnisse innerhalb der Pflanze bedingt sind, mögen die auf Pflanzenwasser gegründeten Bewässerungskriterien weniger durch lokale Verhältnisse beeinflust sein und eher eine fast allgemeine Anwendung haben.

Es werden die zur Untersuchung der Wasserbilanz der Pflanze unternommenen Versuche zusammengefasst und ihre Nützlichkeit für Bewässerungsforschungen und Programmfestlegungen bewertet. Sie umfassen Messungen des Gewebewassergehaltes, der Wachstumgeschwindigkeit, der Spaltöffnung und der Zellensaft-Konzentration. Ferner werden die Blätterfarbe oder sonstige dem Gesichtssinn zugänglichen Indikatoren der Pflanzenwasserspannung und die Verwendung von ausgewählten oder besonders gezogenen, in Ackerfelder eingeführten Pflanzen, in Erwägung gezogen.

DISCUSSION

K. VAN DER MEER (Netherlands). I understood Prof. Hagan well he was mainly discussing the aspect of quantitative plant-production. However, for many crops the qualitative aspect of the product is very important. For instance during ripening of the sugar cane, irrigation has to be very carefully applied in order to keep the sugar content at the highest level. As for fruits like apples taste, shipping and storage quality — and consequently the marketing value— will be affected badly if irrigation is not applied according to physiological stage of development. Has prof. Hagan found any indication regarding this quality problem in his research?

R. M. HAGAN. My paper was intended to consider plant criteria for irrigation scheduling for favorable crop yield and crop quality. Certainly, in many crops quality is important and may determine the marketability of the crop.

J. M. GOSNELL (South Africa). The measurement of moisture content of sheats from the 3rd to 6th leaves has been generally used in sugar-cane agriculture for control of irrigation during the maturation period. A reduction from 78—80 per cent down to 73 per cent moisture in this tissue at harvest has been found to correspond with optimum sucrose accumulation.

W. R. GARDNER (U.S.A.). It appears to me that the use of an indicator plant as you suggest is an indirect attempt to measure the soil water potential. Do you actually find the response of indicator plants to be more highly correlated with crop growth than soil water potential measurements?

R. M. HAGAN. The use of separate plants to indicate irrigation need is but one of the many approaches reviewed in this paper. The use of an indicator plant, or preferably plant measurements, should indicate the water status of the plants which is determined by the differences in rates of water absorption and loss and the length of time over which such differences have persisted. Soil water potential is one factor determining rate water absorption by plants.

The relatively few measurements so far reported in the literature relating plant growth to plant water status indicate that better correlations should be obtained than between plant growth and soil water potential since the latter is but one of several factors determining growth.

I+VI. 1

S. A. TAYLOR (U.S.A.). Prof. Hagan has given a complete listing of possible techniques for scheduling irrigation (time to begin and how much water to apply), and has stated that many of them require more research. Is there any technique that you are willing to recommend for use at this time?

R. M. HAGAN. I have known of no one plant measurement or indicator which can be recomended generally. For certain crops (beans, cotton, grape, palm), at least under given conditions, specific plant indicators have prooved to be successful guides to irrigation need. It should be pointed out that, in some situations, tensiometers have also been very useful, where correlations have been established, under the prevailing conditions, between tensiometer readings and plant growth.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

THE USE OF PHYSIOLOGICAL INDICATORS FOR THE TIMING OF IRRIGATION [1]

E. SHMUELI [2]

INTRODUCTION

Soil scientists, agronomists and plant physiologists engaged in irrigation research have long been attempting to find an answer to a practical question, posed by farmers in irrigated regions: When should the crop be irrigated? A few years ago, according to the theory of Veihmeyer (1956) the answer seemed simple enough: Irrigation should be applied when all the available moisture in the root zone has been exhausted.

However, during the last decade, there has been a growing conviction that plant processes, which depend on water status are not determined exclusively by either soil moisture or climatic conditions, but rather by integrated influence of the energy status of water in the soil and in the atmosphere. This in turn determines the internal water status of the plant. As a consequence, much emphasis has been lately placed on the need for measuring the plant water potential (Kramer, 1963). This was aptly stated at the end of the 19th century by K. A. Timiriazev who argued that in order to determine the needs of the plant, one should ask the plant itself.

More than 30 years elapsed between the time Timiriazev's statements were made and the appearance of the first publications of research in which plant physiological indicators were used for irrigation timing, for example; Magness, Degman and Furr (1935), Maximov and Zernova (1936).

A physiological indicator for the timing of irrigation is based on some physiological procexes (such as growth rate) or some visual symptoms (such as turgidity, color changes) or some plant indexes (such as cell sap concentration, stomatal aperture). All of these may be related to some critical water potential in the plant indicating necessity to irrigate.

In Israel, the first investigations concerning physiological indicators for irrigation were carried out on citrus by Oppenheimer and Elze (1941) and bananas, by Shmueli (1953). During the last decade, the search for physiological indicators becomes an integral part of the irrigation experi-

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[2] National and University Institute of Agriculture, Rehovot, ISRAEL.

ments conducted by the Division of Irrigation of the Volcani Institute, mainly on field crops.

The most promising results obtained in Israel until now are with the use of stomatal aperture as an indicator. Therefore, the discussion will deal primarily with this index.

THEORETICAL CONSIDERATIONS

The most reliable indicator for irrigation need seems to be on theoretical grounds, the energy status of the water in the plant (= hydropotential = water potential = diffusion pressure deficit = suction pressure = = suction tension). However, the current methods of measuring the water potential are not sufficiently reliable (Shmueli, 1964), and the most advanced among them demand conditions of constant temperature which cannot be provided in the field. In the quest for an indicator suitable for field use it should be borne in mind that such an index has to be reliable yet easy and simple to measure. The stomatal aperture measurement answers both these demands. On the other hand, it should be kept in mind that: „Despite a vast amount of effort during more than a century, the mechanism of stomatal movement is not understood" (Ketellapper, 1963). "The only definite statements that can be made are that the mechanism is operated by turgor changes (Heath, 1959).

The latter statement provides a sound basis for using stomatal aperture as an index for evaluating the plant's water status, on condition that the water status is the only determining factor of the turgor changes in the guard and subsidiary cells, when the measurements is being made.

This condition limits the use of the indicator to clear days when the temperature changes are normal. Such a situation exists in Israel and in many other countries during most of the irrigation season. The uniform climatic conditions existing in Israel during the main irrigation season creates the possibility of finding a high correlation between the critical moisture status of the plant and that of the soil which indicates the need to irrigate.

METHODOLOGY

For each crop, several indicators are tested in the preliminary stages of the research. Eventually, one or two most promising indicators are subjected to intensive study, where the various plant responses (growth, yield, etc.) are correlated with the indicators.

Certain precautions are necessary to ensure reliable results. These include use of leaves of similar age, condition and exposure , use of the same region in all leaves, and choice of the proper time of the day at which the tests are made. Some preliminary experimentation (preferably under field conditions) is essential in order to develop the best procedure to be used on a particular species.

For field work, there are today three methods available for direct microscopic measurement of stomatal aperture and two indirect methods. The direct methods are: Lloyd's method (1908), collodion (Buscalioni and Pallacci, 1901) and rubber (Zelitch, 1961) impression methods. The indirect methods are: infiltration (Molisch, 1912) and field porometers (Shimshi, 1963; Moreshet, 1964). An evaluation of these various methods is given elsewhere (Shmueli, 1964).

Lloyd's method is suitable for leaves from which the epidermis can readily be separated (for example: beet, cowpeas, alfalfa). It is possible to obtain good collodion impressions from non-hairy leaves whose stomata are not sunken. Rubber impressions can be obtained from practically all types of plants.

The speed at which samples can be prepared in the field is approximately the same for both the Lloyd and rubber impression methods, and this speed is about twice that for the collodion method.

The infiltration and porometer methods are suitable for leaves bearing stomata on both surfaces, which are connected by a continuous intercellular space system. These methods give best results when the ratio between the number of upper stomata to the number of lower ones is within the range of 1 : 1 to 1 : 3. The infiltration measurements are based on the fact that the rate of penetration of a liquid of low viscosity applied to the stomated surface of a leaf depends chiefly on the size of the stomatal pores. Early investigators used a series of liquids of different viscosities. In the studies reported here, penetration of a single liquid was used and the time required for its infiltration into the leaf was measured. The infiltration method has considerable advantages; it is simple, requires no special equipment, and observations are made simultaneously on thousands of stomata. The main disadvantage is that the technique is to some extent subjective, in judging the exact time of infiltration.

With the porometer, the resistance of the leaf to viscous flow of air is measured. Here again the measurements represent an integrated value of the resistance of thousand of stomata.

Two types of field porometers recently developed in Israel (Shimshi, 1963: Moreshet, 1964) are simple to operate, and permit objective and accurate determination of the leaf's resistance.

With one investigator balancing the differential manometer and recording the needle-value reading, and a second person operating the hand grip leaf cup, ten readings can be made from ten different plants in the course of five minutes. This is approximately the time required for one person to make a similar number of measurements using the small field porometer, or the infiltration method. Table 1 presents some details concerning the infiltration method as applied to three crops.

Since the stomatal dimensions of the three crops mentioned are similar, the calculation of the infiltration index is done following the calibration scale originally developed for bananas by Shmueli (1953).

Table 1

Infiltration fluid, leaf selected and time of day for testing irrigation need on banana, corn and cotton

Plant species	Infiltration fluid	Leaf tested	Region on the leaf, tested	Leaf surface	Age af the plant	Time hr.
Banana Musa Cavendishii	Kerosene	3rd from the top	1/2—1/4 from the tip, central area	Upper and under	From 10 leaf stage to flowering	12^{00} to 13^{00}
Corn Neve-Yahr 21	1 : 2 mixture by volume of paraffin and turpentine	3rd from the top	15—20 cm from the tip, central area	Upper	From 25—30 to 75—80 days after seeding	12^{00} to 13^{00}
Cotton Acala 4—42	Same	3 and 4 th from the top	Central area between mid-rib and leaf margin	Under	After flowering begins	12^{30} to 13^{30}

RESULTS AND DISCUSSIONS

Figures 1 and 2 present results of infiltration measurements on banana, and figure 3 and 4 on cotton. A summary of cotton yield data from an irrigation requirement experiment, including one treatment irrigated in July-August according to the infiltration indicator, is given in table 2

The diurnal changes in infiltration index are markedly affected by the amount of available moisture. As long as soil moisture in the root zone of banana is higher than 70 per cent available water, maximum stomatal

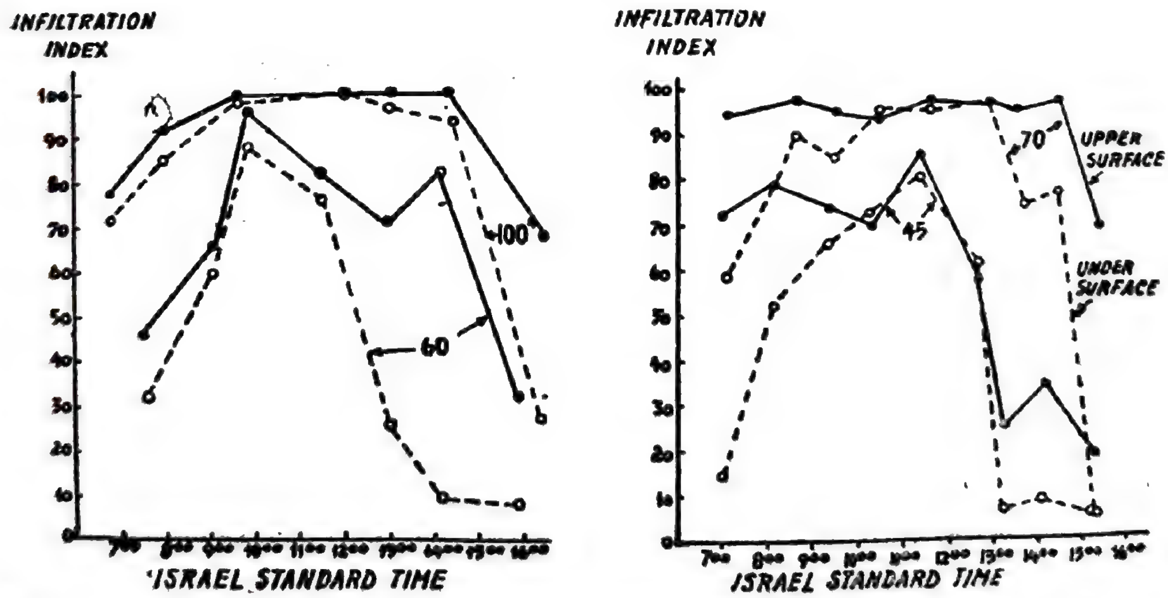

Fig.1 Diurnal variations in infiltration index of banana leaves under conditions of 100, 70, 60 and 45 per cent available soil moisture in the 0—60 cm soil layer.

Table 2

Irrigation regimes and yields of cotton, Esdraelon Valley, 1961

Teatment No.	No. of irrigations	Net water application (mm)	Yields	
			Seed cotton* Kg/du	Fiber Kg/du
1	1	70	118	50
2	2	185	221	88
3	3	390	253	104
4	4	440	284	115
5	5	585	323	131
6	6	565	343	140
7	6	700	335	135
8	8	700	367	147
9	4	420	355	143
10**	6	630	399	162

* dunam = 1000 m².

** Irrigated in July and August according to infiltration test at 12^{30} — 13^{30} hr

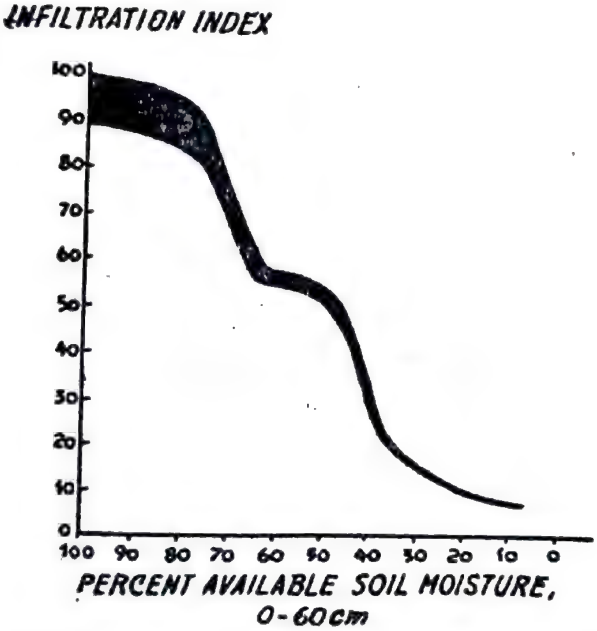

Fig. 2. Relation between infiltration index of banana leaves and the available soil moisture in the 0—60 cm soil layer.

aperture is maintained on both leaf surfaces from early morning till afternoon (fig. 1).

A premature closure of stomata occurs when available moisture drops below 70 per cent. The differences in infiltration index are expecially pronounced during the mid-day hours. In figure 2 are given averages of infiltration indices from about 10,000 measurements made between 12:00—13:00 hours in various banana plantations in the Jordan Valley. The relation between the available soil moisture level and the infiltration index is apparent. In a banana irrigation experiment, a reduction in yield occurred in those treatments where available soil moisture prior to irrigation was less than 65—70 per cent (Stoler,

1952). It therefore follows that threshold soil moisture at which irrigation should be applied can be established by using the infiltration method.

In principle, similar results to the above were obtained with several other crops. For example, figure 3 and table 2 illustrate data from cotton irrigation experiments conducted by Heller, Ophir and Shmueli (1964) in the Esdraelon Valley.

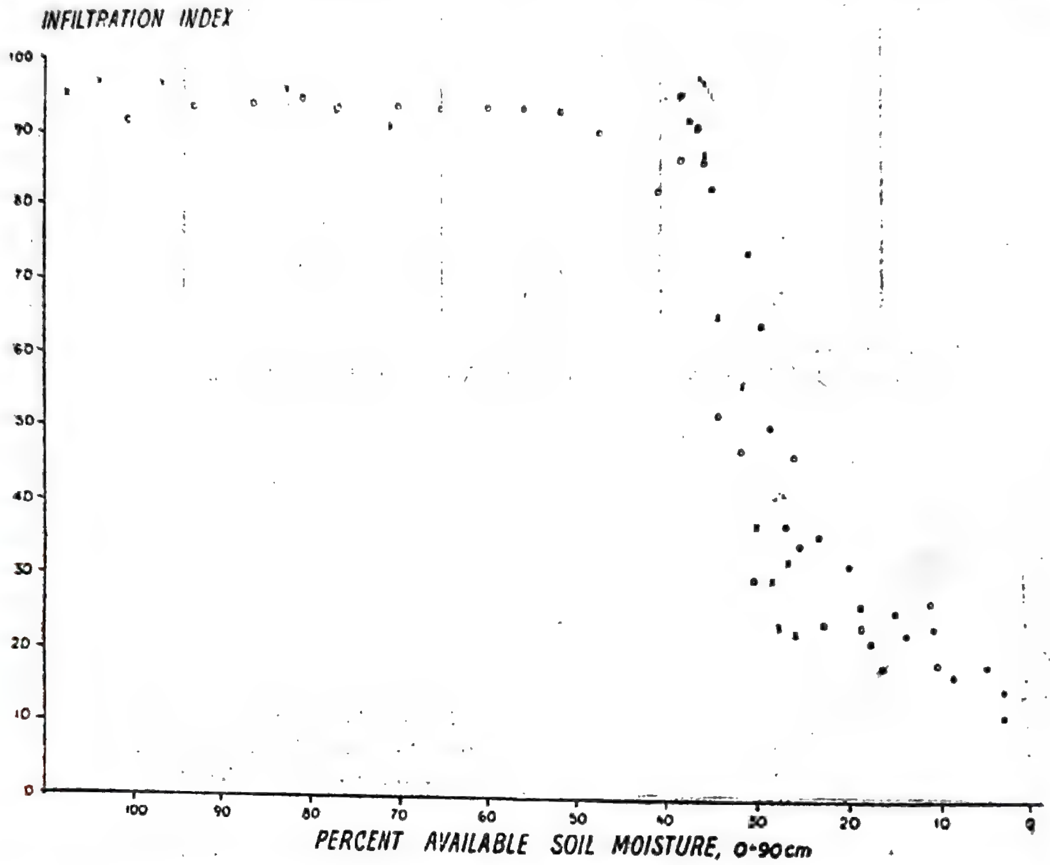

Fig. 3. Relation between infiltration index of cotton leaves and the available soil moisture in the 0—90 cm soil layer.

It appears that after flowering has begun, cotton should be irrigated when soil moisture in the main root zone (0—90 cm) has dropped to 30—40 per cent available water.

The studies carried out in Israel indicate that in general the use of physiological indicators, based on the results of long -term irrigation experiments can aid considerably in correct timing of irrigation. This results in high yields accompanied by an economical utilization of water.

The high yield obtained when irrigation is given according to the physiological indicator is due to the maintenance of ia favourable internal water regime which permits physiological activity unhampered by plant water stress.

Physiological indicators also make possible the extension of the conclusions drawn from the results of studies carried out at one location (orata

limited number of locations), to a wide variety of soils. Thus results of irrig ation research can be applied to large areas.

When working with such indicators on a wide scale, it is quite conceivable that they may sometimes provide unexpected data. This is often a consequence of special conditions oı limiting factors such as nutritional

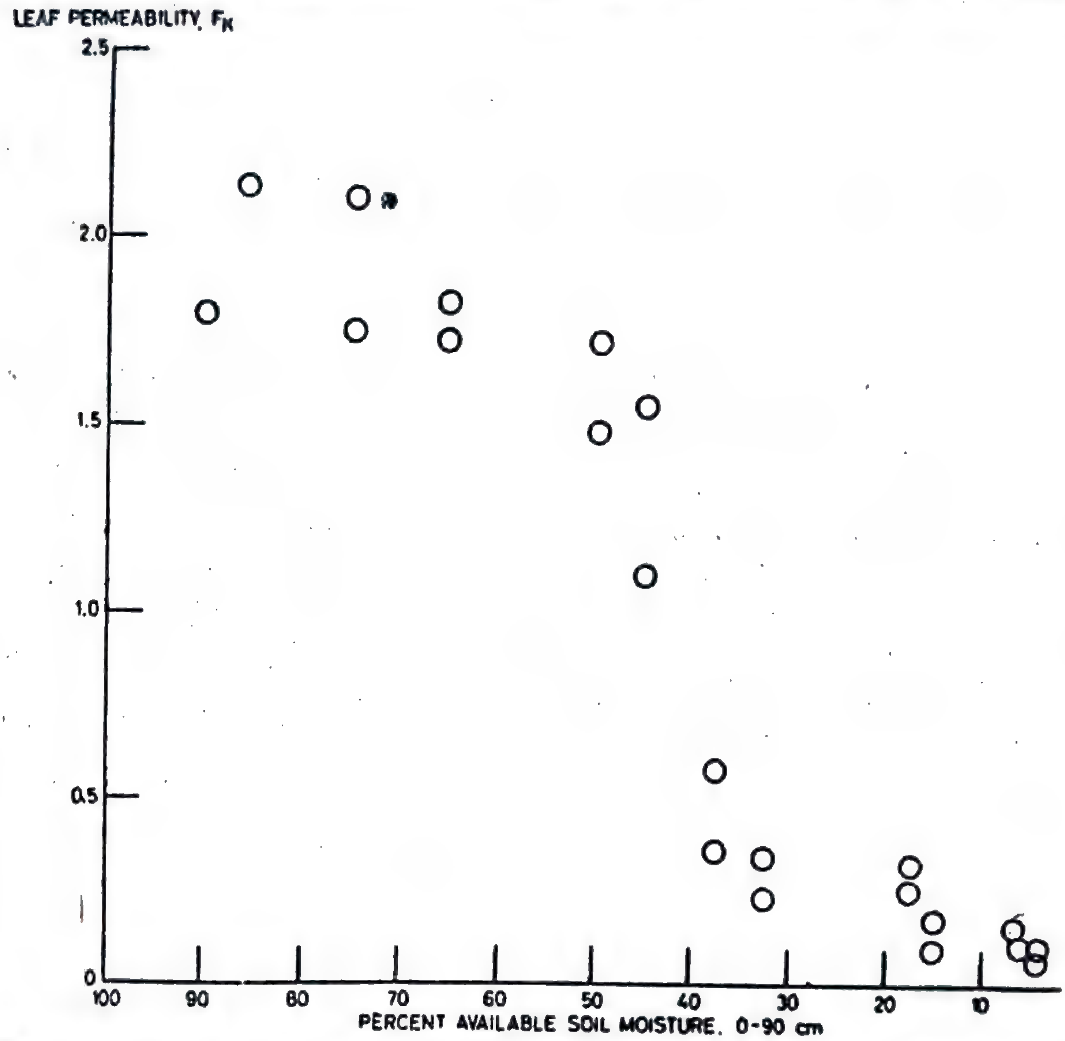

Fig. 4. Relation between permeability of cotton leaves, as measured with a porometer, and th available soil moisture in the 0—90 cm soil layer.

deficiencies, a rise in the water table, a sudden rise in salinity, insect and disease damage, or extreme and unusual climatic conditions. Therefore, whenever the course of the physiological indicator takes an abnormal or unexpected turn, one should suspect that some factor, other than the internal water status, is involved in the crop response.

An experienced research worker can easily notice such abnormal infiltration data, due to the aforementioned factors. Under normal conditions, the results obtained by means of the infiltration method are reliable and reproducible. When, however, this method was used by different persons, such as agricultural advisers and farmers, it was found that results were very

variable, due to personal differences on judging the time of infiltration. This difficulty was known to us some years ago. We hoped that suitable instructions and training of the persons using this technique might improne the reproducibility of the results; this hope has not materialized. Thus, the infiltration method, which in the hands of a skilled research worker may be a reliable and practical indicator for the timing of irrigating, the become almost worthless for this purpose, whenever it is used by numerous persons on a wide scale.

Two scientists of the Irrigation Division have lately begun to develop and adapt several types of field porometers. Of these, two types seem now to provide an easy to operate, and yet reliable tool for indicating the necessity of irrigation according to stomatal resistance, under field conditions.

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SUMMARY

The use of plant indicators enobled the attainment of high yields with economic utilization of water. Under the climatic conditions of the dry summer season in Israel, a high correlation was found between the critical threshold of the plant index, and the critical moisture content of the main root zone, indicating the need for irrigation. The critical soil moisture was not

the same for all tested crops. The stomatal aperture was a very promising indicator for irrigation need. The infiltration method and especially developed field porometers were found to be useful in irrigation timing.

RÉSUMÉ

L'utilisation de plantes indicatrices a permis d'atteindre des productions élevés avec un emploi économique d'eau. Dans les conditions climatiques de la saison d'été sèche d'Israel, on a trouvé une corrélation serrée entre la limite critique de l'indice de la plante et l'humidité critique de la zone radiculaire principale, indiquant la nécessité de l'irrigation. L'humidité critique du sol n'étaitpas la même pour toutes les cultures expérimentées.

L'ouverture des stomates a été un indicateur très prometteur pour la nécessité de l'irrigation.

On a trouvé que la méthode d'infiltration et les poromètres de champ spécialement développés étaient très utiles pour établir les moments d'irrigation.

ZUSAMMENFASSUNG

Die Anwendung von physiologischen indikatorene rmöglichte hohe Erträge bei einer wirtschaftlichen Wasserverwendung zu erzielen. Unter den Verhältnissen der trockenen Sommerjahreszeit inIsrael wurde eine hohe Korrelation zwischen der kritischen Grenze des Pflanzenindexes und de skritischen Wassergehaltes der Hauptwurzelzone gefunden, welche den Bewässerungsbedarf angab. Die kritische Bodenfeuchtigkeit war nicht für alle erprobten Kulturen dieselbe. Die Stomatenöffnung war ein sehr versprechender Indikator für den Bewässerungsbedarf. Die Infiltrations methode und eigens entwickelte Feldporometer wurden zur Zeitbestimmung der Bewässerung für sehr nützlich gefunden.

DISCUSSION

J. M. GOSNELL (South Africa). The use of plant indicators is undoubtedly a big advance in efficient irrigation control. However, when stomatal apertures are used, one must take into account other factors, principally light intensity, which have been shown to affect stomatal opening in many crops. How can this difficulty be overcome when using infiltration and porometer techniques?

E. SHMUELI. The use of stomatal aperture as an indicator of the internal water status of the plant is limited for the time being to regions having no rainfall and few clouds during the irrigation season. While at Duke University in North Carolina, U.S.A., in 1960/61, we examined the possibility of using the infiltration technique as an indicator. The region has summer rains, high relative humidity and many clouds. Under these conditions we encountered many more difficulties than those met in Israel. However, it does seem that the subject is worthy of attention even in places where light intensity and humidity change considerably from day to day during the irrigation season.

THE USE OF THE NEUTRON PROBE TO STUDY MOISTURE MOVEMENT AND MOISTURE EXTRACTION BY SUGARCANE IN HAWAII [1]

F. E. ROBINSON, L. D. BAVER [2]

The neutron probe measures moisture changes in a soil profile beneath a fixed point on the soil surface. This measurement can be made over as long a period as desired. The sampling variation of auger techniques, which require sampling from different points, is avoided. Unlike gypsum blocks and tensiometers, the neutron method does not have a limited range of accuracy. Tedious repetition of calibration efforts is avoided and measurements are obtained with considerably less disturbance to the existing soil profile.

Basically, the neutron probe consists of 1) a radioactive neutron source, 2) an electronic tube to intercept reflected neutrons, and 3) a meter to indicate the number of neutrons which are reflected. As the neutrons are shot out into the soil, they strike the hydrogen nuclei in water and are counted as they rebound to the counting tube. The number of counts received in a given time is calibrated against the volumetric soil moisture.

The advantages and versatility of the neutron probe are well documented Stone et al. (1960) found that the neutron method of measuring soil moisture required approximately 1/7 of the sampling sites of the gravimetric method to have comparable precision of measurement. The equipment has been used under such variable conditions as citrus orchards (Stolzy and. Cahoon, 1957), greenhouses (Twerski and Hillsman, 1961), and weighing lysimeters (McGuinness et al., 1961) ; it has been employed from the Netherlands (Holmes, 1956) to South Africa (Marais a. De Smit, 1960). The Troxler 104 probe with a 2cm Ra-Be source was decribed by van Bavel et al. (1961). This probe is sensitive enough to distinguish two 2.54cm layers only 10 cm apart (McHenry, 1963). The Tempe rate meter described by van Bavel (1962) was found to have a precision of 2 cps (counts per second), which is equivalent to 0.5 per cent moisture. A less sensitive field calibration of the equipment used in this study showed a precision equivalent to $\pm$ 1 per cent moisture (Robinson, 1963). In a comparison of different types of access tubing, Stolzy and Gahoon (1957) found aluminum tubing gave the best results.

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It is the purpose of this paper to discuss the results of three experiments that show the effectiveness of the neutron probe in measuring soil moisture changes. The first discussion describes the moisture drainage in an unplanted plot following irrigation. The second portrays soil moisture withdrawal by 12-month-old sugarcane from a plot which was first irrigated to field capacity. The third pictures soil moisture withdrawal by sugarcane from a plot which was irrigated at less than field capacity.

UNPLANTED PLOT

In Field *A* of the Kunia Substation, Hawaiian Sugar Planter's Association, fifteen aluminum access tubes, each 5.08 cm in diameter and 150 cm long were placed vertically in a 5m × 7 m plot which had not been planted to cane. The soil was Molokai silty clay. It was covered with plastic paper to prevent evaporation and rainfall additions. To prevent lateral movement of water and to keep out the roots from adjoining plots, a sheet of plastic was around the plot in a ditch one meter in depth.

Since there was no distinct horizons in the soil, the plot may be visualized as consisting of five layers, 2 m × 3 m and 30 cm thick, piled one upon another. An average of 15 measurements was used to describe the moisture content of each of these layers.

Measurements were taken three times per week following irrigation.

During the first two weeks, the combination of a 4.3 cm rain and irrigation of the surrounding area caused lateral seepage into the lower depths of the plot and delayed the drainage process. Following the 13th day after irrigation, drainage proceeded according to a precise mathematical sequence in the form reviewed by Wilcox (1959). The equations were of the form $\theta = aT^{-b}$ where θ equals the volumetric percentage moisture, T is the number of days following the initiation of drainage, and a and b are constants (table 1 shows the equations for each layer). Furthermore, both the

Table 1

Drainage equations for five soil layers in Molokai silty clay

Depth of layer below furrow (cm)	Equation	Correlation* coefficient (r)
0— 30	$\theta = 37.3\ T — 0.037295$	0.948
30— 60	$\theta = 37.9\ T — 0.026826$	0.943
60— 90	$\theta = 40.4\ T — 0.021993$	0.921
90—120	$\theta = 45.1\ T — 0.014781$	0.789
120—150	$\theta = 48.7\ T — 0.013688$	0.720

θ = Volumetric percent moisture.
T = Day after drainage initiated.
* Correlation of the decrease of soil moisture with time (Fig. 1).

a and b constants were highly correlated to the height of these layers above the 150 cm base of reference. The correlation coefficient of b values to height was 0.988, for the a values 0.973. The five equations representing the five layers are thus related in a family of curves as follows:

$$\theta = e^{(-0.07073081\, H + 3.941634)}\ T^{-e^{(0.257721\, H - 4.614703)}}$$

where θ = Volumetric percentage moisture,
H = Height of the layer in cm/30.5 above the deepest point of measurement,
T = Days after drainage was established.

The equation was derived from 65 data points; 25 additional points were obtained and analysis of variance showed that the equation described 96.5 per cent of the change in soil moisture that took place after initiation of drainage.

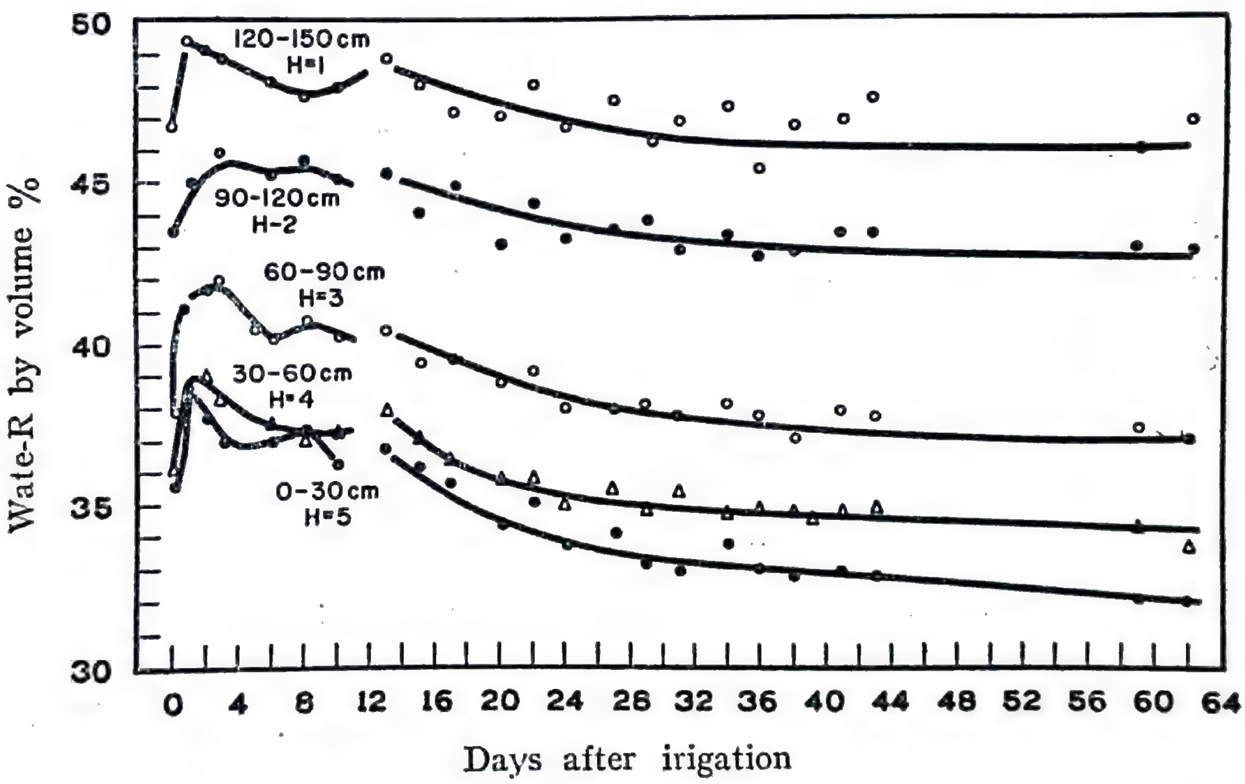

Fig. 1. Moisture changes with depth following irrigation on an unplanted plot.

The moisture changes of each layer are shown in Figure.1. After drainage was established, the moisture content approached a constant value, which was designated the field capacity (table 4).

PLANTED PLOTS

Ten aluminum access tubes were placed vertically to a depth of 150 cm in a 5 m × 7 m plot of 12-month-old cane. Five tubes were placed on a line perpendicular to the furrow in each of two treatment areas. The ends of the furrows in this plot were closed so that water could be ponded at the farthest point to insure attaining field capacity in the first treatment area. The second

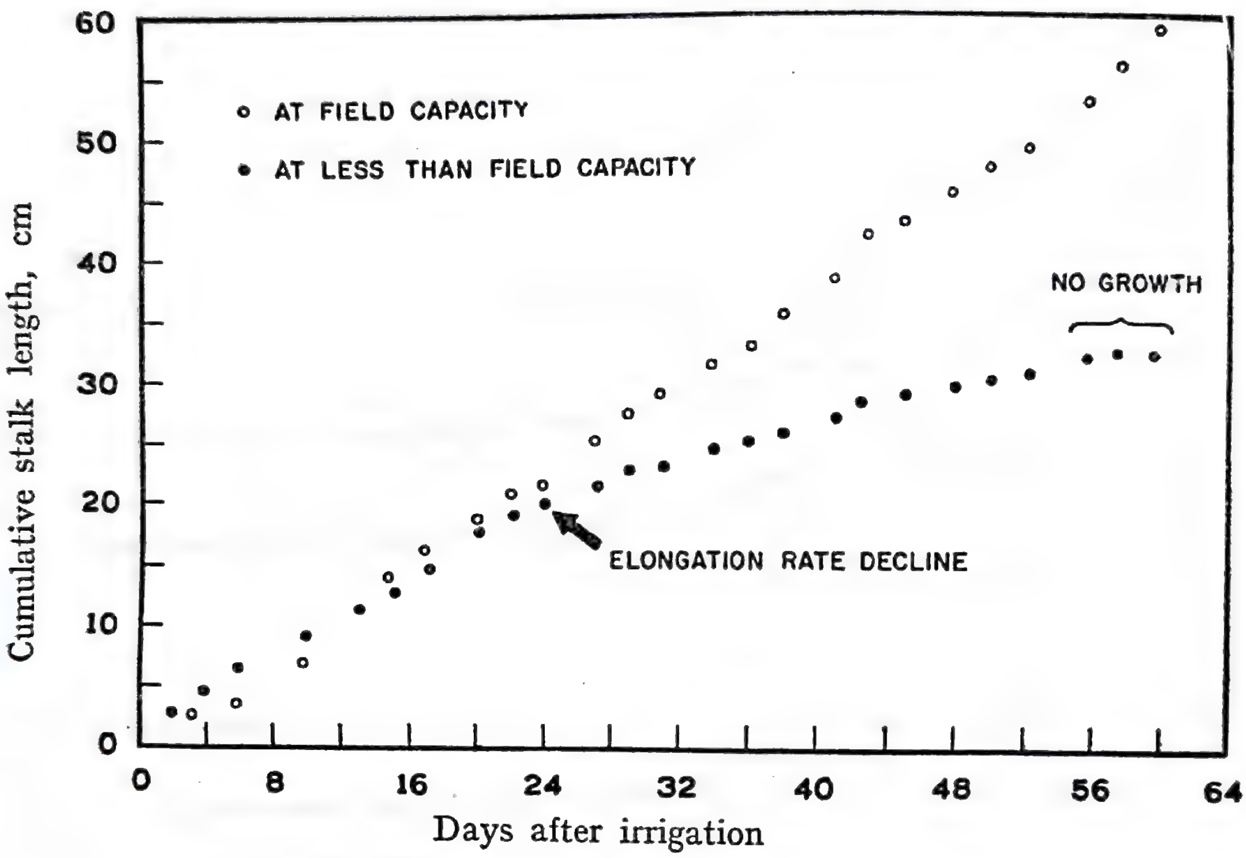

Fig. 2. Stalk elongation of sugarcane following irrigation.

treatment area was above the ponded zone and farther up the furrow. Irrigation in this area brought the soil to less than field capacity. To prevent complications from rainfall and evaporation, the ground surface of the plot was covered with plastic sheeting. This sheeting was fastened around the exposed end of each access tube and each cane stalk. However, during the heavier rainstorms, movement of the cane stalks and the weight of accumulated rain water opened some seams in the plastic sheeting which allowed water to rewet the soil. The times of entry of rainfall are shown clearly by the peaks in the curves of figures 3 and 4. No vertical plastic barrier was placed around the plot of growing cane because of the danger of injury to existing root systems. Consequently, there was some lateral

movement of water into this plot from the surrounding soil. This can also be seen by the peaks in the figures, especially in the lwer layers since there are no corresponding peaks in the top layers. The lateral movement of moisture into the plot negated the possibility of a mathematical analysis of day-to-day changes. However, the relationship between soil moisture and stalk elongation was unaffected. Stalk elongation measurements were recorded three times per week. The relationship between irrigation and elongation is shown in Figure 2. These results will be explained in the following paragraphs.

A 150cm pit was dug in the planted area after completion of the experiment. In order to study root distribution, the soil was gently picked from the roots in a vertical column 15cm wide to the full depth of the pit. This caused the roots to extend about 2 cm from the wall of the pit, which facilitated the counting. The vertical column was divided into 15cm horizons and the roots were counted in each 225 cm^2 increment. Table 2 shows the root count with reference to the bottom of the cane furrow. The rooting pattern was typical of this soil series. The majority of the roots fell within the top 60 cm. The roots density declined in the 60—to 90 cm layer and only channelled rooting occurred in the denser soil below 90 cm.

Table 2

Root distribution and bulk density in Molokai silty clay profile in the planted plot

Depth (cm)	Number of roots per 225 cm^2	Bulk density* (g/cm^3)
30— 15 above furrow	7	1.00
15— 0 above furrow	41	1.01
0— 15 below furrow	54	1.09
15— 30 below furrow	20	1.19
30— 45 below furrow	18	1.14
45— 60 below furrow	13	1.09
60— 75 below furrow	7	1.13
75— 90 below furrow	7	1.14
90—105 below furrow	confined to	1.34
105—120 below furrow	vertical	1.40
120—135 below furrow	channels	1.38
135—150 below furrow		1.38

* Average of six 150—cc cores.

Cane plot where moisture reached firld capacety. The moisture extraction from the different depths of the soil planted to cane followed a different pattern than the unplanted plot. Moisture was removed from the top layer first. After the top layer reached a given moisture percentage, the moisture content of the second layer dropped below field capacity. The sequence of extraction from the different layers is shown in table 3.

Moisture changes in the first treatment are shown in figure 3. The third layer (60 to 90 cm) shows a number of points of increasing moisture percentage which correspond to periods when lateral seepage entered the plot.

Table 3

Sequence of moisture extraction in planted plots which reach field capacity

Soil layer (cm)	Days after irrigation to reach field capacity	Moisture content of plane above when specific layer fell below field capacity (per cent)
0—30	3	—
30—60	7	30
60—90	7	32
90—120	Indefinite	36
120—150	Indefinite	42

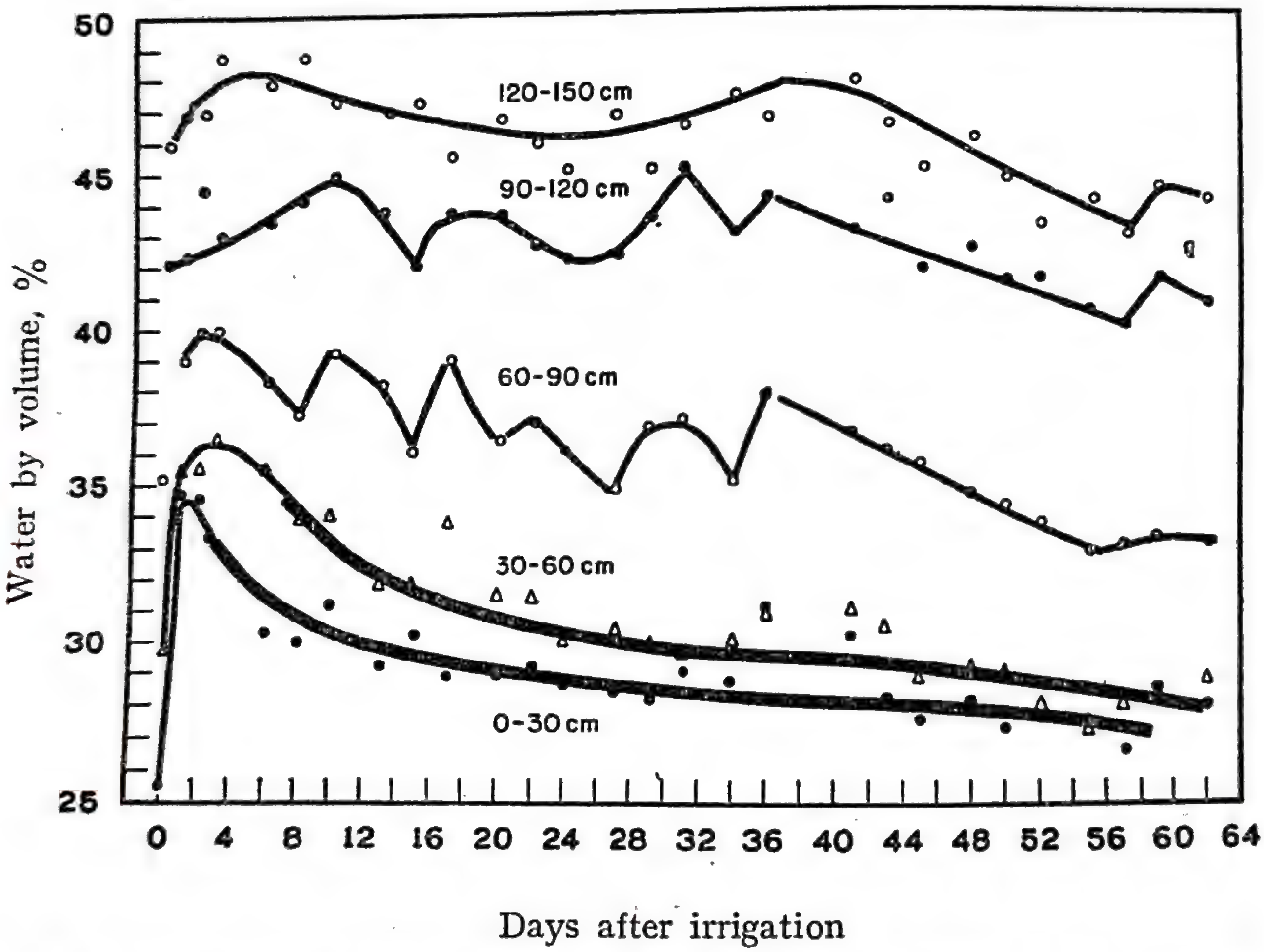

Fig. 3. Moisture changes with depth following irrigation to field capacity of a plot cropped to sugarcane.

The period from the 45th to the 55th day is of particular interest. Here the moisture content of the top layer remained practically constant. The amount of moisture in the second layer dropped about 1 per cent in this 10day period. The third layer exhibits a linear decline of about 0.24 per cent per day (r^2 = 98 per cent). In the fourth layer, this decline was 0.21 per

cent per day ($r^2 = 80$ per cent). In the fifth layer, it was 0.26 per cent per day ($r^2 = 83$ per cent). The rate of moisture drop in the entire profile was approximately 0.23 cm per day. The stalk elongation rate (fig.2) was constant, indicating that water was not limiting growth. It is interesting to note that this daily moisture decrease of 0.23 cm throughout the profile is considerably

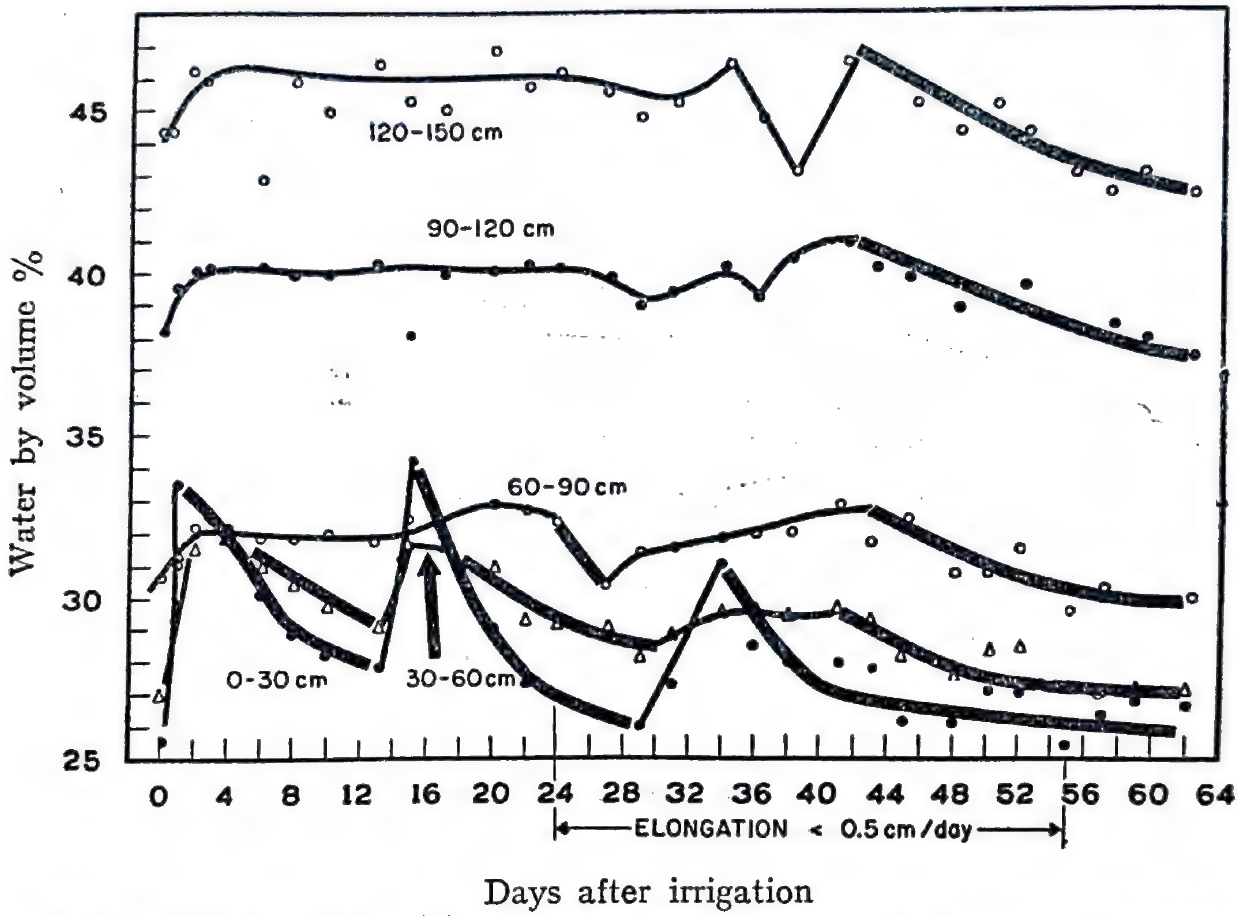

Fig. 4. Moisture changes with depth following irrigation to below field capacity of a plot cropped to sugarcane.

less than the evaporation of 10.48 cm per day from a standard United States Weather Bureau pan. Since previous research (Chang et al. 1963) has shown that evapotranspiration and pan evaporation are practically equal after the cane has established a full canopy, one must consider the possibility of water moving laterally into the profile from adjacent soil to help explain this difference. This is particularly pertinent in light of the fact that there was no decrease in the growth rate of the cane. The neutron-probe measurements in Figure 3 point out rather clearly that there was an increase in soil moisture in both the 60to 90 cm and 90 to 120 cm layers on the 10th, 17th, and 27th day after irrigation. This suggests that a rather substantial quantity of water was made available to t e plant through lateral movement into the plot. This did not occur in the treatment area where irrigation was

below field capacity. It is also evident that water which was supplied by the lower depths was just as effective in maintaining the growth rate as moisture supplied by the top 60 cm.

Cane plot where moisture did not reach field capacity. In the second cane treatment area, the irrigation was not sufficient to bring all depth levels to field capacity (fig.4). The top layer (0 to 30 cm) was the only one to exceed field capacity. The second layer was close to field capacity. However, the lower depths remained almost as dry as they had been prior to irrigation. Withdrawal of moisture from the two top layers continued in much the same manner as in the wet first treatment but dropped to lower moisture values before they levelled off.

On the 24 th day, the stalk elongation rate declined from 0.76 cm per day to an average of 0.36 cm per day (from fig.2) This corresponds to the point where all soil layers in the profile had been reduced to a moisture percentage inadequate to maintain the original rate of growth. The moisture percentage at which the stalk elongation rate declined and at which elongation ceased is shown in table 4. Table 4 also shows the field capacity, available water values, and the soil moisture tension corresponding to each moisture value. Values between 0 and 60 cm of tension were determined from a tension table (Hoover et al., 1954) ; values between 1/3 and 15 atmospheres were determined on a Richards pressure membrane (Richards, 1941). The very low tension values shown at the 90-to 150-cm depths suggest that moisture moved from this zone to the layers above by capillary action. Growth was restricted when the 30—60 cm layer was near 2 atmospheres as observed elsewhere (Robinson, 1963, 1964; Robinson et al., 1963).

Table 4

Effect of soil moisture upon stalk elongation.

Soil layer (cm)	Field capacity (per cent)	Volumetric percentage soil moisture		Available moisture (cm)	
		Elongation rate declines	Elongation ceases	Elongation rate constant = 0.76 cm/day	Elongation rate greater than 0
0—30	32.7 (0.62 atm)*	27.0 (4.0 atm)	26.0 (6.0 atm)	1.73	2.03
30— 60	33.7 (0.51 atm)	28.7 (2.3 atm)	27.0 (4.9 atm)	1.52	2.03
60— 90	37.5 (0.17 atm)	32.5 (0.56 atm)	30.0 (1.1 atm)	1.52	2.29
90—120	43.1 (0.04 atm)	39.2 (0.57 atm)	38.0 (0.66 atm)	1.24	1.55
120—150	46.8 (0.013 atm)	45.1 (0.015 atm)	43.0 (0.023 atm)	0.51	1.17
			Total	6.52	9.07

(*) = Soil moisture tension.

DISCUSSION

The neutron probe has made possible the highlighting of the effect of extremes in the application of irrigation water. Where too little water is applied the growth of cane may be restricted much sooner than the calculated soil moisture storage would indicate. If excess water is applied, lateral seepage may occur, allowing unrestricted growth for a period longer than the calculated soil moisture storage would indicate.

If the full soil moisture storage is to be utilized effectively for plant growth sufficient time must be given during each irrigation to allow all soil layers to come to field capacity. The drier of the two cane treatments in this study received a 30 minute irrigation, which allowed only the top 60 cm to come to field capacity. Growth was restricted in a comparatively short time because the lower depths were not recharged with available moisture.

The observance by the neutron probe of lateral movement of water into cane plots many days after irrigation opens a new phase of investigation of soil moisture in Hawaii.

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SUMMARY

Drainage from an unplanted plot of soil followed a definite mathematical sequence. Field capacity was designated as the moisture level at which the daily decreases in moisture became insignificant.

When cane growth occurred on a soil where all levels of the soil were irrigated to field capacity, extraction of moisture also followed a definite sequence. Moisture was withdrawn from the topmost layer first. As each level approached a definite value, extraction of water from the next lower level commenced. Water which was supplied by the lower depths was capable of maintaining stalk elongation rates at the same level as moisture supplied from the top 60 cm.

When irrigation did not bring all levels of the soil to field capacity, extraction continued to a point where all soil strata were at a limiting moisture percentage. At this point, elongation rates dropped as moisture was continually withdrawn at the drier level. The soil finally reached a dryness at which the elongation rate ceased.

The neutron meter was able to measure field capacity, available moisture storage to maintain unrestricted elongation, and available moisture storage to maintain limited rates of elongation. In addition, evidence indicated that lateral movement of moisture may provide significant quantities of water to growing cane in some Hawaiian soils.

The neutron probe is not recommended as a tool to control irrigation interval during the normal sequence of plantation irrigations. However, where changes in irrigation practices are contemplated, this equipment can provide much-needed information on soil moisture storage and lateral movement of water.

RÉSUMÉ

Le drainage depuis un terrain non planté suivait une séquence mathématique précise. La capacité au champ a été désignée comme le niveau d'humidité auquel la décroissance quotidienne en humidité devenait insignifiante. Quand la croissance de la canne à sucre se produisait sur un sol où tous les niveaux du sol étaient irrigués la capacité au champ, l'extraction de l'humidité suivait également une séquence précise. L'humidité a été extraite d'abord de la couche de surface. Quand chaque niveau approchait une valeur définie, commençait l'extraction de l'eau du niveau immédiatement inférieur. L'eau qui a été fournie par les couches profondes était capable de maintenir la vitesse de croissance de la tige au même niveau que l'humidité fournie par les 60 cm de la surface. Quand l'irrigation n'a pas humecté tous les niveaux du sol à la capacité au champ, l'extraction continuait jusqu'à un point où toutes les couches du sol étaient à un coefficient d'humidité limitatif. À ce point, la vitesse de croissance baissait du fait que l'humidité était extraite continuellement vers le niveau le plus sec. Le sol atteignit finalement une sécheresse à laquelles la vitesse de croissance a cessé.

La sonde à neutrons était capable de mesurer la capacité au champ, l'emmagasinage d'eau accessible capable de maintenir la croissance sans restriction, et l'emmagasinage d'eau accessible capable de maintenir la vitesse de croissance. Au surplus il y avait des indices que le mouvement latéral d'humidité pouvait fournir des quantités importantes d'eau pour faire croître la canne à sucre sur certains sols de Hawaï.

La sonde à neutrons n'est pas recommandée comme un instrument pour régler l'intervalle d'irrigation pendant la séquence normale des irrigations d'une plantation. Néanmoins, là où on envisage des changements dans la pratique de l'irrigation, cet équipement peut fournir des informations très nécessaires sur l'emmagasinage d'eau accessible et sur le mouvement latéral de l'eau.

ZUSAMMENFASSUNG

Die Dränung aus einem unbepflanzten Bodenschlag erfolgte nach einer bestimmten mathematischen Folge. Die Feldkapazität wurde als der Feuchtigkeitsgrad bezeichnet, bei dem die tägliche Abnahme der Feuchtigkeit unbedeutend wurde. Wenn das Wachstum des Rohrs auf einem Boden stattfand, wo alle Bodenhorizonte bis zur Feldkapazität bewässert waren,

dann folgte der Wasser entzug gleichfalls eine bestimmte Sequenz. Das Bodenwasser wurde zuerst aus der obersten Schicht entzogen. Sogleich jeder Horizont einen bestimmten Wert erreichte, begann der Entzug des Wassers aus dem gleich darunterliegenden Horizont. Das durch die tieferen Lagen gelieferte Wasser war imstande die Geschwindigkeit des Halmwuchses auf dieselbe Höhe zu erhalten, wie das von den oberen 60 cm gelieferte Wasser.

Wenn die Bewässerung nicht alle Bodenhorizonte bis zur Feldkapazität gebracht hat, hielt der Wasserentzug bis zu einem Punkt an, wo alle Bodenschichten einen begrenzenden Feuchtigkeitswert erreichten. Bei diesem Punkt sanken die Wuchsgeschwindigkeiten, zumal das Wasser fortdauernd nach das trockenere Niveau entzogen wurde. Endlich erreichte der Boden eine Trockenheit, bei der die Wuchsgeschwindigkeit stillstand. Der Neutronemesser war imstande die Feldkapazität, die Aufspeicherung von verfügbarem Wasser, das imstande ist einen uneingeschränkten Wuchs zu erhalten, und die Aufspeicherung von verfügbarem Wasser zur Erhaltung von begrenzten Wuchsgeschwindigkeiten, zu messen. Überdies gab es Anzeichen, die andeuteten, dass die Seitwärtsbewegung des Wassers erhebliche Wassermengen für den Bau von Zuckerrohr in manchen hawaiischen Böden liefern kann.

Die Neutronensonde ist nicht als ein Gerät empfohlen, um die Bewässerungsabstände während einer normalen Folge einer Pflanzungsbewässerung zu regeln. Dennoch kann diese Ausrüstung, dort wo eine Änderung in der Bewässerungspraxis beabsichtigt wird, sehr notwendige Aufschlüsse über die Bodenwasserspeicherung und über die Seitwärtsbewegung des Wassers geben.

THE USE OF THE NEUTRON MOISTURE METER AND LYSIMETERS FOR WATER BALANCE STUDIES

J. W. HOLMES, J. S. COLVILLE [1]

In an investigation of the hydrology of a part of southern Australia, it was necessary to determine the evaporation from pasture and the drainage through the soil to the water table. The region is a plain near the sea, with an area of about one million hectares. It is composed of limestone rocks, laid down when the Tertiary sea invaded the River Murray region (Sprigg, 1952). The hydraulic conductivity and the depth of the limestone deposits are large enough to enable the natural drainage of the land to be achieved by flow in this aquifer. Rivers and streams do not exist, but there are abundant springs at the sea coast. The aquifer is recharged by infiltration of rain water through the soil to the water table, which is found commonly at a depth of about 3 m.

The rainfall exceeds current evaporation during winter and spring, which are the seasons for crop and pasture growth, without irrigation. Summer and autumn are dry and the average annual rainfall of 70 cm is less than the potential evaporation for the year.

The soils of the region are varied, but there is a large area of meadow podzol, whose profile of 60 cm of sand overlying about 3 m of clay, rests upon the upper surface of the limestone. At a site on such soils, in extensive pasture land, a water balance experiment was conducted, to determine the components, precipitation, P, evaporation, E, drainage D, and increment of soil moisture storage, ΔS, of the balance equation

$$P = E + D + \Delta S$$

METHODS

The site of the experiment was 500 km from the laboratory and the apparatus was therefore arranged so that it could be inspected and measurements made on a routine basis about every four weeks.

The ground water rises to within 2 m of the soil surface during the winter. Therefore lysimeters must be used to separate the soil water from the ground water. The drainage, D, can then be measured directly. The lysimeters were nonweighable and soil water content was measured with the neutron moisture

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meter. Granted that this reduces the accuracy, nevertheless the advantages are that they are cheaper, require little maintenance and deep lysi eters are feasible.

Two lysimeters, made from 3.2 mm sheet steel plate, 1.95 m diameter (area 3 m^2) by 2.4 m deep, were buried and refilled with the soil from the excavation. The rim protruded 3 cm above the soil surface, to contain any surface run-off. The first layer packed in the lysimeter comprised coarse gravel, followed by fine gravel and then sand, the total thickness of this graded filter being 20 cm. Then the soil material itself was repacked in the correct order to reproduce as nearly as possible, the original soil profile.

When packing the soil, four vertical bore-holes were incorporated whose lining was made from 6 cm O.D. polythene pipe. The lower end of these rested on the bottom of the lysimeter ; the top protruded 5 cm above the soil surface. Two of these tubes were open-ended, from which water could be pumped or in which the water level could be measured. Two were sealed and these served as access tubes for the probe of the neutron moisture meter.

Two other lysimeters, identical in every other respect except that they were 1.8 m deep, were installed in nearby irrigated land.

Each lysimeter had tensiometers placed at depths 10, 20, 30, 50, 100 and, in the deeper lysimeters, at 200 cm and gypsum blocks at 10, 20, 30 and 50 cm to measure the soil water suction.

All ancillaries to the lysimeters were placed below soil surface level in an effort to minimise the effect of obstructions upon the wind profile over the lysimeters. The site was flat and the nearest large obstructions to the wind, a solitary tree and the small field laboratory, were about 100 m distant.

The pasture was re-established on the lysimeters by return of the original sod, by re seeding, and by weeding. Cattle and sheep were allowed to graze at will, and, for farming operations, the lysimeters were treated as part of the larger field. The pasture species comprised grasses and clovers.

The neutron moisture meter (*N.M.M.*) used in the experiment was essentially the same as apparatus used in an earlier experiment described by Holmes (1956), and the technique of measurement has also been described (Holmes and Jenkinson, 1959). The probe circuit was designed to drive a cable 100 m long, by which the probe was connected to the main apparatus. The latter, with other equipment, was housed in a small field laboratory. Electrical power at 240 V a.c. was available.

The water content of the soil profile, S, above the graded gravel and sand layer was measured with the *N.M.M.* The probe was lowered by 30 cm increments and each observation was taken to be the mean water content of a layer of soil 30 cm thick. Near the surface however, the first measurement was reckoned to be the mean of 25 cm above the source (i.e. to the soil surface) to 15 cm below the source placement. There was rarely a strong gradient in water content near the surface, as revealed by the tensiometers and gypsum blocks. The results were not corrected for any such error, which was small, though it would have been possible to do so.

The water content of the soil profile, S, was obtained by summation. The increment, ΔS, for an interval of time, is an element of the water balance equation.

The drainage, D, was identified with the total of the volume of water pumped from the lysimeter and the volume accumulated on the bottom of the lysimeter. The latter volume was determined from the measured height of water, and from a calibration of the lysimeter for specific yield. The pumping was called on automatically, by the operation of a suitable electrical circuit, when the water table in the lysimeter reached a determined height, about 1.2 m from the surface. The pumped water was collected in storage drums, buried in the soil nearby, for subsequent measurement. Electrical power at 32 V d.c. was available for these operations.

The rainfall was measured in standard 8-inch raingauges (20 cm diameter) The catch was measured at intervals of about one month, and evaporation of the water in the gauge was suppressed by keeping a layer of light oil, about 2 cm deep, in the vessel, on top of any water there.

The evaporation from the land surface was assumed to be that quantity which would balance the equation (p. 445) for the interval of time under consideration.

ESTIMATE OF ACCURACY

1. *Rainfall*

Four raingauges were used. One was placed near the two lysimeters in the unirrigated field and three were grouped near the irrigated lysimeters about 200 m distant.

Over a period of a year, there was no consistent difference between the monthly gaugings. The scatter of results indicates that the standard deviation was larger in the wet months than in the dry. For five wet periods (see table 5, to be discussed later) with a minimum rainfall of 5.3 cm the *S.D.* assigned is 0.15 cm. During the other five periods in which the rainfall varied between 0.4 and 2.3 cm the *S.D.* was 0.05 cm. This was a relatively small contribution to the random error in assessing evaporation.

2. *Limitations in measuring* ΔS

The major contribution to random error in estimation of evaporation comes from the measurement of soil water content. Counting of slow neutrons is subject to the familiar Poisson statistical variation and therefore contributes an unavoidable error in the estimation of soil water content. Increasing the number of counts recorded reduces the relative error. In this work, the count rate at each probe depth was obtained from the total counts recorded in five minutes, or until 10,000 counts had been recorded if this took longer than five minutes. The counting was always divided into two or more intervals, whose sum was (say), five minutes to provide a check, at once, upon gross reading errors.

The standard deviation of total soil water content, S, was calculated on the basis of Poisson theory for typical soil moisture profiles. The *S.D.*

increases with increase in soil water content. For a profile water content of 50 cm the $S.D$ was 0.08 cm, and for a profile water content of 73 cm it was 0.095 cm.

A further source of variation in the soil water measurements comes from error in the placement of the probe, and short-term repeatability of the *N.M.M.* readings. The variation from this cause was determined by making replicate measurements in the same hole. In one sequence of measurements, the same hole was measured six times. Five estimates of profile water content gave a mean of 48.38 cm with *S.D.*, of 0.17 cm. The sixth measurement differed from the mean by 5 times the *S.D.*, which suggests that it should be rejected, though the reason for the error is not known. Two weeks later the measurement of profile water content was repeated 16 times, in the same hole. The mean profile water content was 47.19 cm with *S.D.* of 0.18 cm. All sixteen observations lay within two *S.D*'s from the mean. Errors associated with placement of the probe in the bore hole do not appear to be large. Note that the 16 measurements to a depth of 2.1 m in the profile took two days to complete and are therefore also a check on short-term stability. To reduce the effect of drift in counting rate, the apparatus was normalised with the probe in water, every half hour. The probe was accurately located in the tube in the water-drum, by using an aluminium strip to hold it in a reproducible position against the tube wall, since the probe diameter was 4.4 cm and the access tube diameter was 5.3 cm. When in the bore-hole in the soil, the probe was allowed to hang freely, on its cable.

Notwithstanding the estimate of *S.D.* just given, there was considerable variation in the increment of water content from hole to hole. As an example, the water content increments, ΔS, of the profile to a depth of 2.25 m, determined at holes 5 and 6, both in lysimeter *L*3, are shown in table 1.

Table 1

Increments of soil water content, measured in holes 5 and 6, lysimeter L3

Period ending	ΔS_5	ΔS_6	$\delta = \Delta S_5 - \Delta S_6$
13 Feb. 1963	−0.86	−0.20	−0.66
13 Mar.	−3.04	−4.20	+1.16
10 Apr.	−1.33	−0.55	−0.78
8 May	+0.73	−0.40	+1.13
1 June	+4.86	+6.39	−1.53
3 July	+4.10	+4.76	−0.66
31 July	+10.19	+9.89	+0.30
24 Aug.	+0.81	+2.45	−1.64
23 Sept.	+3.91	+1.95	+1.96
18 Oct.	−9.71	−8.46	−1.25
12 Nov.	−5.54	−4.77	−0.77
10 Dec.	−7.81	−7.00	−0.81
15 Jan. 1964	−2.18	−4.27	+2.09
18 Febr.	−0.36	+0.30	−0.66
Totals	−6.23	−4.11	−2.12

The scatter in increments was large, and the over all changes in the water content from hole to hole were not statistically significant. The scatter, shown as ($\Delta S_5 - \Delta S_6$) is much larger than is to be expected if the *S.D.* is 2σ, where σ is the *S.D.* for one profile, S, including probe placement error. Formal test shows that the ratio of the two variances is significantly large at the 0.1 per cent limit of confidence.

The reasons for these large variations are obscure, at present. There is no doubt that the rates of drying of the soil profile, from site to site, were different, from time to time. Possibly different activity of roots, pests and pathogens on the roots, different stages of maturity and height of the pasture above ground have all contributed to a non-uniformity of the pasture as far as increments of soil water are concerned. However, this variation must be included in the estimate of error in the average evaporation.

Holes 7 and 8 in lysimeter *L*4 show similar scatter (table 2). Pooling the two estimates of variance, we get *S.D.* of 1.0 cm for the increment in soil water content, ΔS. The observed differences between the two lysimeters are not significant, and their results may be treated as true duplicates.

Table 2

Increments of soil water content, measured in holes 7 and 8, lysimeter L4

Period ending	ΔS_7	ΔS_8	$\delta = \Delta S_7 - \Delta S_8$
13 Febr. 1963	+0.85	+0.90	—0.05
13 Mar.	—3.70	—4.18	+0.48
10 Apr.	—0.75	—0.27	—0.48
8 May	—0.96	—1.64	+0.68
1 Iune	+5.52	+5.53	—0.01
3 July	+3.56	+3.36	+0.20
31 July	+13.24	+12.07	+1.17
24 Aug.	+0.67	+0.78	—0.11
23 Sept.	+6.43	+7.40	—0.97
18 Oct.	—8.60	—9.50	+0.90
12 Nov.	—5.56	—7.17	+1.61
10 Dec.	—9.32	—9.36	+0.04
15 Jan. 1964	—3.77	—3.03	—0.74
18 Feb.	—0.61	—0.77	+0.16
Totals	—3.00	—5.88	+2.88

Two access holes, *C* and *D*, were drilled in the undisturbed soil, and the water content of the soil profile was also determined by *N.M.M.* in these holes, down to the natural water table.

Comparison of the soil water profile inside the lysimeter with the soil water profiles outside the lysimeter shows a systematic difference. The external holes were always wetter than the lysimeters, except for the top 60 cm of the profile during the dry period. This suggests, that in repacking the lysimeters, too much clay became mixed accidentally into the top 60 cm and too much sand into the lower portion of the profile.

The increment of soil water content, ΔS, is relevant for the water balance equation. Table 3 shows the increment of soil water to a depth of 2.25 m. It will be seen that the difference in the monthly increments is erratic. Formal test shows that the difference between the overall increase for the two holes is not significant. There is therefore, no reason to distinguish between two holes.

Table 3

Increments of soil water content, measured in holes C and D, undisturbed soil

Period ending	ΔS_C	ΔS_D	$\delta = \Delta S_C - \Delta S_D$
13 Feb. 1963	−1.68	−1.59	−0.09
13 Mar.	−2.08	−1.61	−0.47
10 April	−0.89	−1.83	+0.94
8 May	−0.73	−0.08	−0.65
1 June	+3.93	+5.46	−1.53
3 July	+4.77	+4.06	+0.71
31 July	+12.82	+12.86	−0.04
24 Aug.	+2.29	−1.01	+3.30
23 Sept.	+4.20	+4.48	−0.28
18 Oct.	−9.24	−11.09	+1.85
12 Nov.	−6.49	−5.15	−1.34
10 Dec.	−7.57	−4.42	−3.15
15 Jan. 1964	−2.19	−2.02	−0.17
18 Feb.	+1.24	+1.56	−0.32
Totals	−1.62	−0.38	−1.24

The variance of δ for the holes C and D is greater than that for the four lysimeter holes. For the data included in table 1, 2 and 3, the variance ratio is not significant at the 1 per cent level. However, if results between 12 December 1961 and 18 February 1964 are pooled, the variance is 1.21 sq. cm. for the lysimeters and 4.97 sq. cm. for the external holes. The ratio is significant at the 1 per cent level. It can therefore be concluded that the scatter of ΔS, already commented upon for the lysimeters, is not a result of repacking. Instead, repacking has significantly reduced it. This result is understandable if the scatter is due to soil or plant differences, which have been spread more evenly when the soil was repacked.

Formal test shows that the difference between the means of soil water increment for holes C and D and the four lysimeter holes is not significant. Nor does the monthly difference, during the whole period 12 December 1961 to 18 February 1964, show any systematic trend, season by season, or any systematic correlation with either rainfall or water table depth in the current or previous month.

3. *Limitations in measuring drainage.*

The drainage, D, through the soil profile, was a small component of the water balance. More water always drained through the profile in lysimeter $L3$ than drained through $L4$, as can be seen from the results in table 4. But

difference in the drainage was always small except for one month near the end of the winter. Excluding this period the *S.D.* is 0.2 cm, which is smaller than the *S.D.* of ΔS.

Table 4

The drainage (cm) through the soil profiles in lysimeters L3 and L4

Period	*L3*	*L4*	Rainfall
May 1961 to Jan. 1962	3.02	2.08	38.6
May 1962 to Jan. 1963	4.44	2.54	56.8
May 1963 to Jan. 1964	4.37	2.53	42.9

It follows therefore that the random error in ΔS predominates over all other uncertainties in estimating E. In the present case, E is determined from the mean of four holes, and therefore will have *S.D.* of 0.5 cm.

It is reasonable to suppose that all lysimeters, even if weighable, would exhibit similar variation in the estimation of evaporation. The results of Harrold and Dreibelbis (1958) show a scatter of monthly evaporation for the weighable lysimeters 102C and 103A (table 21) in three separate years of „meadow second year" with *S.D.* of 1.0 cm. The Coshocton lysimeters are monoliths with area 8.1 sq. m., whereas the probe of the *N.M.M.* effectively samples a cylinder of 0.3 sq. m. area. On the basis of sampling theory and our figure for the *S.D.* for undisturbed soil, a value of 0.4 cm would be predicted for the Coshocton lysimeters.

RESULTS

An example of the water balance, for part of the period studied is shown in table 5. The total drainage was a small part of the total balance. This has a practical importance if large scale irrigation from the water-table is contemplated. Increment of mean soil water content for the four holes was often the largest part of the total balance.

The evaporation, determined by difference, was comparable with its own *S.D.* on three occasions.

The significance of these results in relation to other hydrological data for the region will be discussed in another publication.

Table 5

The water balance of pasture land, February to December, 1963, determined in lysimeters

Date (1963)	P (cm)	D (cm)	ΔS (cm)	Evaporation (cm)	Evaporation rate (mm/day)
13 Feb. to 13 Mar.	0.5	—0.2	—3.8	4.5	1.6
13 Mar. to 10 Apr.	1.5	—0.1	—0.7	2.3	0.8
10 Apr. to 8 May	0.5	—0.1	—0.6	1.2	0.4
8 May to 1 June	5.7	—0.1	+5.6	0.2	0.1
1 June to 3 July	6.0	—0.1	+4.0	2.1	0.7
3 July to 31 July	12.3	—0.2	+11.3	1.2	0.4
31 July to 24 Aug.	5.3	+1.3	+1.2	2.8	1.2
24 Aug. to 23 Sept.	8.9	+2.3	+4.9	1.7	0.6
23 Sept. to 18 Oct.	0.4	+0.2	—9.1	9.3	3.7
18 Oct. to 12 Nov.	2.3	+0.1	—5.8	8.0	3.2
12 Nov. to 10 Dec.	0.5	—0.1	—8.4	9.0	3.2
Total for period	43.9	+3.0	—1.4	42.3	

Acknowledgments

Mr. J. W. Harvey, Technical Assistant, assisted with the field work and Mr. M. W. Hughes, Technical Officer, C.S.I.R.O, in addition to field work, was responsible for much of the water balance calculations.

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SUMMARY

Four lysimeters, each 3 m² in area, were buried in pasture land, for investigations of the water balance at the land surface. They were unweighable but their water contents were determined with the neutron moisture meter. The overall accuracy obtainable allowed water gain or loss of 0.5 cm to be resolved. There was a variability in the increments of soil water content, greater than instrumental error, which remains unexplained.

RÉSUMÉ

Quatre lysimètres, chacun ayant une superficie de 3 m², ont été enterrés dans un sol de pâturage pour des recherches du bilan de l'eau à la surface de la terre. Ils ne sont pas pesables mais la teneur en eau a été déterminée à l'aide de l'appareil à neutrons pour la détermination de l'humidité. La précision générale obtenue a permis de déceler les pertes ou les gains d'eau d'une valeur de 0,5 cm.

Il y a eu une variation dans l'augmentation de la teneur en eau du sol, plus grande que l'erreur instrumentale qui demeure inexplicable.

ZUSAMMENFASSUNG

Vier Lysimeter, jeder von 3m²-Fläche wurden für Wasserbilanzuntersuchungen in der Bodenoberfläche in Weideland eingegraben. Die Lysimeter waren nicht wägbar, aber ihre Wassergehalte wurden mittels des Feuchtigkeitsmessers mit Neutronen bestimmt. Die allegemein erreichbare Genauigkeit ermöglichte einen Wassergewinn oder-verlust von 0,5 cm zu ermitteln. Es gab eine Schwankung in der Zunahme des Bodenwassergehaltes, grösser als der durch das Gerät verursachte Fehler, was unerklärt bleibt.

DISCUSSION

S. A. TAYLOR (U.S.A.). I agree with the conclusion that the neutron probe can be used to indicate the amount of water in the soil and the amount of water removed from the soil. However, a careful analysis of slide 2 from Dr. Baver's paper indicates a variation that I would

like to discuss. Even in the shallow depths, where latent movement of water is not likely, there are periodic increases in water content. We have observed that metal access tubes, that are exposed to direct radiation, warm and cool much more rapidly than the soil. As a result we have observed condensation of water drops on the inside of metal tubes on a cool morning following a hot day, that became cool during night. This condensation of water was accompanied by an apparent increase in soil water. There may have been condensation also in the soil adjoint to the cool tube. Presumably, the opposite effect would be found in the evening following a day of bright sunshine.

J. W. HOLMES. In our experiments, we are using plastic access tubes, and it is possible that they avoid the inconvenience mentioned by Dr. Taylor.

L. D. BAVER (U.S.A.). It is possible that the peaks in the curve may be due to phenomena other than the movement of water laterally. Condensation of moisture, as Dr. Taylor has suggested, could have been a factor. In a more recent experiment these peaks could not be verified (the latter data were not available at the time of the Bucharest meeting).

S. A. TAYLOR. We are presently investigating the use of plastic tubes to alleviate this problem, but the results are not yet complete. We are also investigating the use of a 15 cm length of plastic on the exposed end of the access tubes.

D. KIRKHAM. (U.S.A.). Dr. Holmes finds rather large and unexpected moisture differences from location to location in his soils. Perhaps he would not find them so unexpected if he would see the data on some of our Iowa soils. In Research Bulletin No. 465 of the Iowa Agricultural and Home Economics Experiment Station; Iowa State University, Ames, Iowa, a bulletin entitled „An Evaluation of Some Soil Moisture Characteristics of Iowa Soils", data is shown that moisture percentages vary from 2 to 10. Even on the Edina soil, which is supposed to be the most uniform soil in our state, the percentages from spot to spot varied as much as from 2 to 10 per cent. Examination of the mechanical texture of the soil showed that this varied greatly too, which may account in part for the large differences. This publication gives detailed variations in moisture content from depth to depth for a range of soils from coarse to fine textured.

A. R. BERTRAND (U.S.A.). At what soil moisture tension did rate of plant elongation slow down?

L. D. BAVER. At about 2 bars.

J. M. GOSNELL (South Africa). The relationship of elongation to soil moisture content and its extraction at various depths is most important to sugar-cane agronomists. However it has been found in South Africa that various other factors (light intensity, temperature) have important effects on elongation when soil moisture conditions are optimum. How was it possible to separate these effects in this study?

Will the relative quantities of moisture extracted by different depths of soil (compare 0—30 cm and 120—150 cm) be significantly affected by varying temperature gradients at these depths at different times of year?

As regards Dr. Taylor's comment, I wonder how is it possible that a thin film (perhaps 1/2—1 mm thick) of condensed moisture on the access tube can significantly affect the moisture reading of the neutron probe which integrates over a sphere of 20—50 cm diameter?

L. D. BAVER: a) It is very difficult to separate the moisture, light intensity and sublight effects. We find that the lower temperatures during the winter months as well as these occuring at the higher elevations decrease the rate of elongation. At the same temperature, elongation is greater the higher the solar energy.

b) There are no temperature gradients of significance at these depths.

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I+VI. 5

QUELQUES ASPECTS PÉDOLOGIQUES DE L'IRRIGATION

M. BOTZAN [1]

Par la pratique de l'irrigation le sol reçoit et accumule l'eau d'irrigation et la transmet aux plantes dans la zone de développement maximum des racines. Ce sont donc les propriétés du sol caractérisant ces fonctions qui nous intéressent en premier lieu.

La technique actuelle de l'irrigation ne permet pas de maintenir continuellement dans le sol une humidité constante, au plafond théorique optime. C'est pourquoi en pratique on se réfère au plafond minimum de l'humidité du sol. Intervenant par des arrosages périodiques, on se limite à considérer comme optime l'humidité du sol qui est au dessus de ce plafond minimum.

Le régime de ces interventions périodiques, qui est élaboré en se basant sur la connaissance des besoins des plantes et des conditions spécifiques du sol, du climat, de l'hydrogéologie etc., constitue le régime de l'irrigation.

Donc les aspects pédologiques ont un rôle important dans toutes les étapes de la compréhension et de l'application de l'irrigation.

Nous allons faire ressortir plus loin quelques aspects pédologiques actuels pour la technique de l'irrigation.

LE RÉGIME DE L'HUMIDITÉ DU SOL ET LA RÉCOLTE

Un indice synthétique et expressif de la proportion de la capacité au champ pour l'eau qui est accéssible aux plantes, pour un certain type de sol, est le rapport entre la valeur de l'intervalle de l'humidité active (Fc-Wp) et la capacité au champ pour l'eau (Fc), c'est à dire $100\,(Fc\text{-}Wp)/Fc$.

L'analyse de cet indice, que nous avons nommé *coefficient de la capacité active*, montre une baisse continue de sa valeur en partant des sables des dunes semi-mobiles (81%), jusqu'aux lacovichtés très lourdes (35%), simultanément avec la croissance de la proportion de l'argile (particules $< 0{,}002$ mm). Une corrélation, ayant le même sens, peut aussi être constatée avec le coefficient de l'hygroscopicité, respectivement avec le coefficient de flétrissement Wp (fig. 1).

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La texture du sol détermine la courbe de corrélation entre la succion, exprimée par le pF, et l'humidité du sol. La figure 2, avec le schéma de cette corrélation pour trois catégories texturales de sol, montre aussi le schéma de

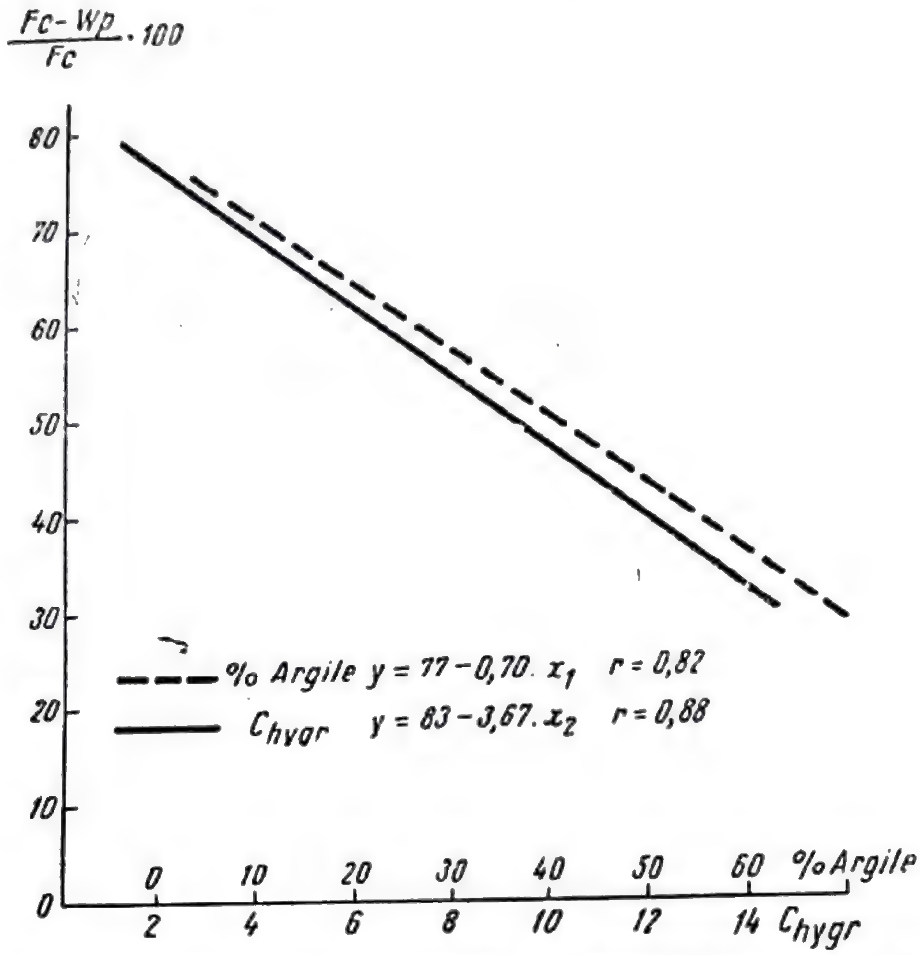

Fig. 1. Corrélation entre le coefficient de la capacité active (y) et le pourcentage de l'argile (x_1) ou le coéfficient d'hygroscopicité (x_2).

la corrélation entre la récolte et le pF, respectivement *rendement-humidité du sol*. L'intervalle de la variation de l'humidité du sol, pour une certaine proportion de la récolte maxima, a été déterminé entre l'humidité maxima (la capacité de saturation) et entre l'humidité minima (le point de flétrissement).

L'humidité accéssible du sol est le facteur déterminant pour la consommation productive de la part des cultures, ainsi que pour l'évaporation de la surface du sol. Les études faites dans les conditions de l'irrigation dans la Plaine du Danube Inférieur, sur la corrélation entre la consommation de l'eau du sol par évapotranspiration et l'humidité accéssible du sol, ont montré une corrélation de forme lg $y = a + b \cdot x$ entre la consommation journalière (y) et l'humidité accéssible (x) pendant un certain mois de la période de végétation (Botzan et Cioică, 1963). Les courbes mensuelles de corrélation ont des positions différentes suivant la zone pédoclimatique.

Les consommations croissent, pour la même humidité accéssible, de mai jusqu'en juillet (dans le chernozem châtain jusqu'en août), pour tomber brusquement en septembre, se maintenant tout de même au dessus du niveau du mois de mai. Surtout pendant les mois de juin-août, la consommation est

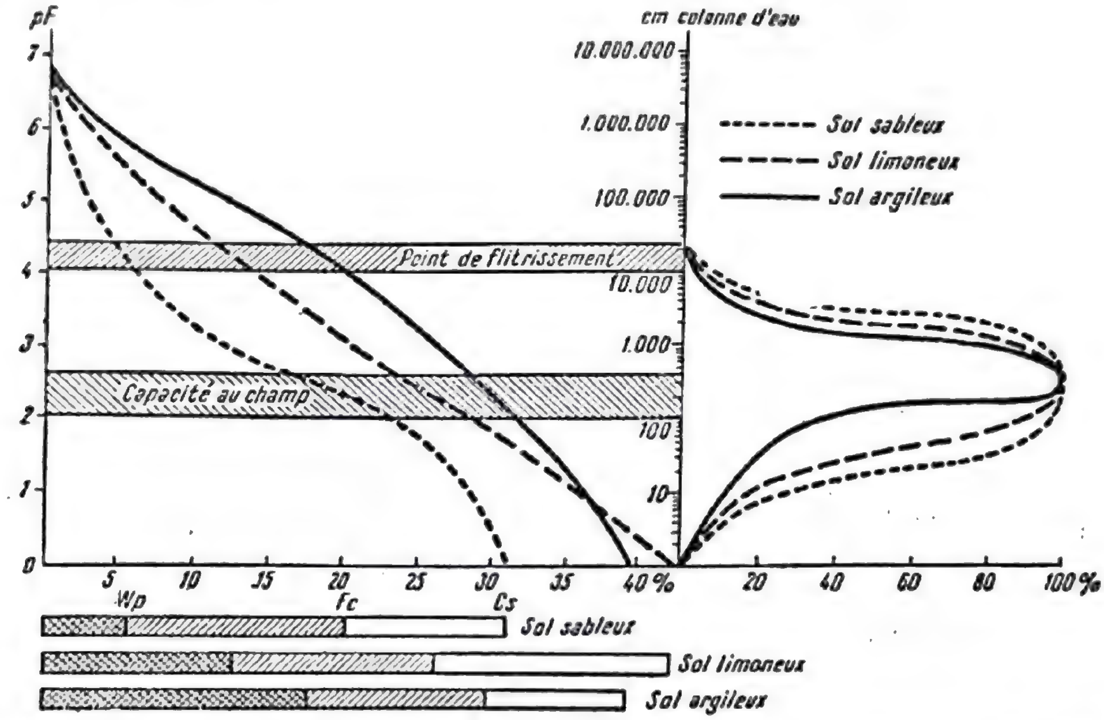

Fig. 2. Schéma de la corrélation pF-humidité du sol et pF-rendement pour trois catégories texturales de sol.

plus grande dans le chernozem châtain que dans le sol brun-roux de forêt, pour la même humidité accéssible. Ces différentiations plaident pour la validité des méthodes de corrélation de la consommation avec les éléments climatiques, la méthode de Thornthwaite par exemple.

Ces études ont fait ressortir d'une façon très claire l'influence du complexe des facteurs de zone sur la corrélation récolte-consommation dans les conditions de l'irrigation. On a constaté ainsi, que les productions les plus économiques du point de vue de la consommation de l'eau sont obtenues sur le sol brun-roux de forêt en comparaison avec les sols de steppe, grâce, en premier lieu, à la réduction des pertes d'eau non productives.

La limite inférieure admissible de l'humidité accéssible, respectivement *le plafond minimum* de l'humidité du sol nécéssaire pour obtenir de riches récoltes, correspond du point de vue pédologique à une valeur caractéristique de l'humidité, l'interruption de la continuité des liens capillaires. Les pédologues soviétiques ont nommé ce point „l'humidité de ralentissement de la croissance" (Rodé, 1956).

Les nombreuses recherches expérimentales faites dans la Plaine du Danube Inférieur, sur des sols zonaux à texture moyenne, formées sur du loess,

nous orientent vers un plafond minimum qui se trouve approximativement au centre de l'intervalle de l'humidité active.

Il existe des indications expérimentales et pratiques, qui montrent que dans des sols sablonneux ce plafond peut être abaissé jusqu'à approximativement 1/3 de l'intervalle de l'humidité active, tandis que dans des sols argileux on doit le considérer comme étant à peu près 2/3 de cet intervalle.

Cette différentiation du plafond influence les normes d'arrosage, l'intervalle entre les arrosages et même les méthodes d'arrosage. Pour avoir des précisions il est nécessaire d'entreprendre des études expérimentales supplémentaires, en actionnant probablement surtout dans le domaine du pF.

ASPECTS LIÉS AU CALCUL DES NORMES D'ARROSAGE

Pour le calcul des normes d'arrosage pendant la période de végétation on prend en considération le sol (par la capacité au champ, par la provision momentanée d'eau — et respectivement le plafond minimum - et par le poids volumétrique), la plante (par la profondeur d'humectation correspondant à la masse principale des racines) et le climat (par les pertes pendant l'arrosage, qui doivent être compensées par la norme d'arrosage).

Le problème du calcul des normes d'arrosage n'est pas complètement résolu, même du point de vue pédologique, quoique ce soit un domaine plus concret que les deux autres. En laissant de coté le plafond minimum, qui a été discuté, il faut montrer qu'il y a encore des difficultés liées aux autres éléments pédologiques entrant dans la formule de calcul des normes d'arrosage.

Ainsi, en ce qui concerne le poids volumétrique, même si on sait en général qu'il varie avec l'humidité du sol, on ne connait pas dans quelle mesure cette variation influence le calcul des normes d'arrosage.

À l'occasion de l'étude plus approfondie de la technique de l'arrosage par rigoles et plates-bandes, faite sur du chernozem châtain dans la Plaine du Danube Inférieur, on a vu que la profondeur d'humectation calculée a été en fait dépassée d'une façon évidente (Renea et Unceanschi, 1959; Unceanschi et Renea, 1959). De cette façon , l'eau infiltrée au dessous de la couche active (considérée dans le calcul) a été comprise, dans une longue série d'expériences, entre 15 et 29% de la norme d'arrosage.

Ces différences importantes pour la répartition de la norme d'arrosage calculée le long du profil sont attribuées spécialement à la différence entre la valeur de la capacité au champ déterminée par les méthodes classiques et la valeur réelle de la capacité au champ dans le cas de l'irrigation d'un horizon de sol limité à 0,5—1 m (selon la culture), sous lequel le sol est sec. En réalité, dans le premier cas il s'agit d'une capacité au champ maximum, soutenue sur une sous-couche humidifiée au moins jusqu'à la capacité au champ. Donc, pour éclaircir ces aspects fondamentaux de l'irrigation de nouvelles études sont encore nécessaires.

La différentiation de la norme d'arrosage selon la zone pédoclimatique est due surtout à trois éléments qui varient avec la zone : le plafond minimum, les constantes physiques et hydrophysiques, ainsi que la profondeur de développement des racines. Dans une plus petite mesure intervient aussi le quantum des pertes durant l'arrosage (lié au climat ainsi qu'à la méthode d'arrosage).

La dynamique de l'humidité du sol de deux champs de maïs dans deux zones pédoclimatiques différentes est comparée dans la figure 3. Les schémas a_1 et b_1 donnent la situation en régime naturel, tandis que a_2 et b_2 dans les conditions de l'irrigation avec des normes relativement petites (400—600 m^3/ha). On observe visuellement le fait confirmé par l'effet économique, que les arrosages avec de petites normes et répétés souvent ne sont pas recommandables dans la steppe sèche (a_2) alors que sur des sols bruns-roux de forêt (b_2) ils produisent dans ces conditions une humidité dépassant le plafond minimum jusqu'au commencement de l'automne, à 1,20 m de profondeur.

Si en général sur les sols extrêmement sablonneux ou argileux, surtout en passant vers des zones plus humides, les normes d'arrosage doivent aller des moyennes jusqu'aux petites (650—350 m^3/ha) sur les sols à texture moyenne, surtout quand on passe vers des zones plus sèches, les normes d'arrosage doivent être moyennes jusqu'à grandes (650—1 200 m^3/ha). Pour le premier cas on recommande spécialement l'aspersion, pour le second l'arrosage par rigoles et plates—bandes, évidemment si les autres conditions plaident aussi pour l'une ou l'autre des méthodes d'arrosage.

Pour le calcul des normes d'approvisionnement appliquées en automne on prend comme élément de base le coefficient d'utilisation des précipitations d'hiver. Les études faites dans la Plaine du Danube Inférieur ont montré sous cet aspect des différentiations très importantes selon la zone pédoclimatique (Botzan, 1963). Ainsi sur les champs de maïs , dans les conditions naturelles, les précipitations d'hiver sont utilisables dans une proportion sensiblement plus petite sur des sols brun-roux de forêt (coefficient moyen 0,26), en comparaison avec la zone sèche (coefficient 0,43—0,61), ce qui nous fait douter de l'utilité des arrosages d'approvisionnement en dehors de la zone sèche.

Dans les conditions d'irrigation le coefficient d'utilisation est moindre, surtout après les cultures qui sont irriguées jusqu'à la fin de la période de végétation (maïs, et surtout la betterave à sucre et la luzerne). Un rôle important dans la modification de ce coefficient, par la modification de la conductibilité hydraulique du sol, est joué par les basses températures de l'hiver et spécialement par le gel.

Effectivement, les arrosages d'approvisionnement (a) ne sont pas nécessaires dans une zone quand la différence entre la capacité en eau au champ (Fc) et la réserve finale d'eau dans le sol (Rf) en automne est égale ou plus petite que les précipitations d'hiver utiles ($c.\ Pi$), c'est à dire les précipitations d'hiver (Pi) multipliées par le coefficient d'utilisation (c). Donc $a = 0$ quand $Fc - Rf \leqslant c \cdot Pi$.

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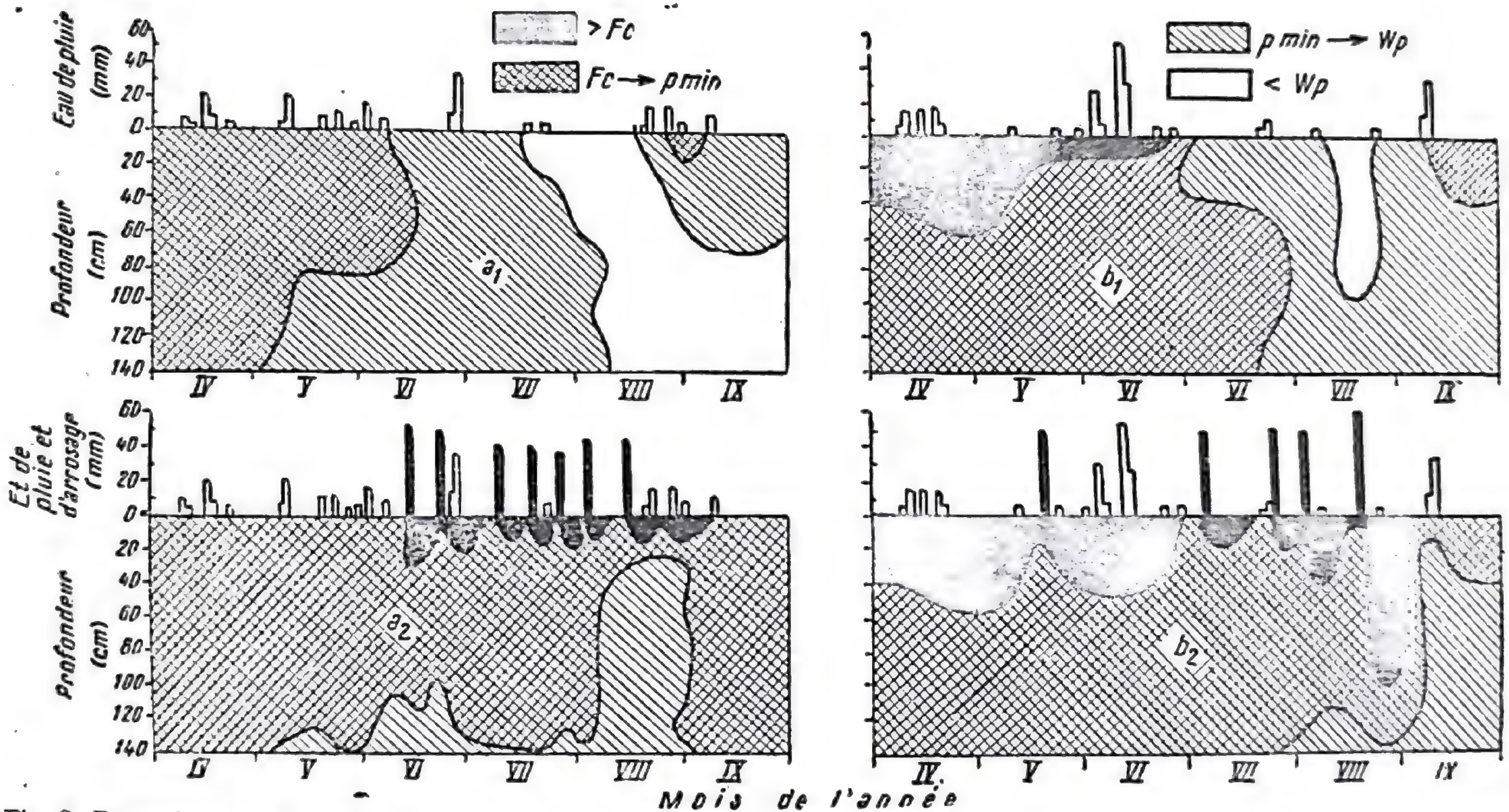

Fig. 3. Dynamique de l'humidité du sol pour des champs de maïs, dans un chernozem châtain carbonaté (a_1, a_2) et dans un sol brun-roux de forêt (b_1, b_2), dans les conditions naturelles (a_1, b_1) et celles de l'irrigation (a_2, b_2).

En se basant sur les éléments du bilan de l'eau du sol, déterminés par des expériences dans la Plaine du Danube Inférieur, on voit que dans la zone sèche il faut en moyenne des arrosages d'approvisionnement d'automne avec des normes allant de 900 m³/ha jusqu'à zero, vers la limite de la zone sous-humide (la transition est faite par le chernozem très lévigué). Dans la zone sous-humide, sur un sol brun-roux de forêt l'arrosage d'approvisionnement n'est pas nécéssaire; toutefois en certaines automnes il se peut qu'il soit nécéssaire d'arroser seulement pendant les semailles du blé, à une petite profondeur.

En conclusion on peut dire que:

— pour caractériser synthétiquement des fonctions importantes du sol dans la technique de l'irrigation, le coefficient de la capacité active est un indice utile;

— comme la texture différencie cet indice, elle différencie aussi la nature de la corrélation entre la récolte agricole et le pF;

— le plafond minimum de l'humidité du sol est une notion fondamentale dans la technique de l'irrigation: on a réussi à lui donner un fondement théorique, il faut encore élargir le sens de cette notion pour englober les catégories texturales extrêmes de sol;

— de nouvelles données expérimentales sont nécessaires pour caractériser plus complèment des constantes comme le poids volumétrique et la capacité en eau au champ, qui participent directement au calcul de la norme d'arrosage;

— le coefficient d'utilisation des précipitations d'hiver est un indice fondamental pour le calcul de l'arrosage d'approvisionnement; les études climatologiques peuvent apporter des données importantes pour sa précision.

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RÉSUMÉ

On propose, en rapport avec la fonction du sol d'emmagasiner l'eau d'irrigation, un indice expressif: le coefficient de la capacité active qui est en corrélation avec la teneur en argile et le coefficient de flétrissement.

Des considérations sont faites concernant les rapports entre la succion, l'humidité accessible, la quantité d'eau du sol consommée et la production agricole.

On signale la nécessité de certaines études supplémentaires, tant pour la limite inférieure de l'humidité accessible que pour quelques propriétés du sol constituant un élément de base dans le calcul des arrosages.

SUMMARY

In connection with the water storage function of the soil, an expressive index is proposed: the active capacity coefficient, related to the clay content and to the wilting coefficient. Correlations between suction, available moisture, soil water consumption and crop-yeld are also discussed.

The need for supplimentary studies concerning the lower limit of available moisture as well as some basic soil properties affecting the water requirement is pointed out.

ZUSAMMENFASSUNG

Im Zusammenhang mit der Funktion des Bodens Bewässerungswasser aufzuspeichern wird ein ausdrucksvoller Index, nämlich der Koeffizient der aktiven Kapazität, vorgeschlagen, der mit dem Tongehaltprozentsatz und dem Welkungskoeffizienten in Korrelation steht.

Es werden die Beziehungen zwischen Saugspannung, verfügbares Wasser, Bodenwasserverbrauch und landwirtschaftliche Produktion erörtert.

Es wird die Notwendigkeit zusätzlicher Studien über die Mindestgrenze des nutzbaren Wassers sowie über einige Bodeneigenschaften, die die Berechnung der Berieselungsnorm bestimmen, hervorgehoben.

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THE CONCEPT OF "ACTUAL FIELD CAPACITY" AND ITS APPLICATION TO THE INTERPRETATION OF FERTILIZER TRIALS UNDER IRRIGATION

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It is very frequent that fertilization trials of irrigated crops are affected by a serious experimental error. This error is a consequence of marked differences in yield, or in other biological parameters, between replicates of the same treatment. This experimental error makes the interpretation of the results difficult and prevents that clear tendencies of response to some of the treatments under trial be considered as statistically significative.

However, the variation among blocks may be changed from an annoying obstacle into an „aid to soil science", as suggested by Collis-George and Davey (1960), if instead of taking this variation as an inevitable consequence of errors arising from field experiments, the implied challenge is accepted. In other words, a positive attitude would try to individualize and, if possible, to quantify, which properties of the soil that was supposed to be homogenous are involved in the observed variations.

In irrigated fertilizer trials there are, at least, the following factors which may be responsible for variations between replicates:

a) distributional heterogeneity of the native form of the tested element or elements in the soil. That is to say, the existence in the same field of sites with high and low natural fertility levels for the implied elements. This circumstance influences specially the variability of the blank treatment; although, when the tested fertilizer dosis are not elevated (i.e., not sufficient in themselves to raise the available level to an optimum one) the alluded circumstance may also cause yield differences between replicates of the fertilizer treatments:

b) heterogeneity in the distribution of nutrients others than the tested ones. This effect may be neutralized to a certain degree, when adding these complementary nutrients to all the plots;

c) heterogeneity in the distribution of damaging substances as, for instance, insoluble salts;

d) plot differences in morphological characteristics of soil profile that might influence in root development and soil-water relations;

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e) Microrelief differences between plots that might affect irrigation efficiency. These two last factors are, perhaps, the most important ones in irrigated fertilizer trials. It has been proved by several authors that soil water potential, *per se* or by its influence on nutrient absorption, acts upon plant growth.

Stanhill (1957) reviewed most of the pertinent literature in question and concluded that 80 per cent of the papers reported a favorable response of crops to the wettest irrigation regimes, i.e. those regimes which assured a low average matric suction. When only annual crops were taken into account this percentage was found to be still higher.

Brown and Place (1959), Brown et al. (1960) and Bennett, et al. (1960) found a positive correlation beetween nutrients (N, P, K and Ca) absorption by cotton and soil moisture. A similar effect of phosphorus absorption by oat was reported by Simpson (1960).

Doss et al. (1960) discovered a favourable influence of the nitrogen-soil-moisture interaction on grass yields. Olsen et al. (1961) demonstrated that P uptake by corn seedling was a linear function of the soil mois ture content for a given soil.

Fawcett and Quirk (1962) working with wheat consider that „the efficiency of phosphorus utilization was not markedly affected by increasing water stress, provided the plants were not damaged by wilting, but water stress *per se* was limiting growth". However, Mederski and Stackhouse (1960) employing the split-root technique have been able to prove that the decrease of nutrient uptake by maize — following the increase in soil water matric suction — was independent of the plant water stress, which was kept low because part of the root system supplied enough water to meet evapotranspiration requirements.

It is obvious, then, that if in an irrigated fertilizer trial the replicates of the same treatment have different conditions in what regards the average water potential, those differences, which are independent of the tested treatment must necessarily influence the yields: directly through the action of the soil moisture stress on the plant and/or in affecting the efficiency of the fertilizers. Differences in the average water potential may arise when, after watering, the amount of water stored by the soil layer of maximum root activity is not the same for every plot.

The final problems of this paper are the following: a) to report the possibility that differences in microrelief and infiltration rate provoke differences in the storage of water, even in plots of an apparently homogeneous soil which are under the same irrigation practice; b) to propose the concept of *Actual Field Capacity* (*AFC*) to define the upper available water content for a given site (plot) under a given irrigation practice, and c) to point out the influence of *AFC* on yields, its importance as a cause of variations between replicates and the possibility of diminishing the experimental error through the *AFC* determination before the layout of the experiments.

THE CONCEPT OF ACTUAL FIELD CAPACITY

The *Field Capacity (FC)*, which is the practical upper limit of available water is not a true constant and its value does not depend only upon edaphic characteristics but also upon the amount of water applied and the time when the determination takes place.

As Gardner (1960) has stated, "it (*FC*) can only be precisely defined in terms of the method of measurement, in which case the concept loses much of its utility". Already Colman (1944) found that the water content in the upper soil layer retained after rainfall or irrigation depends on the total wetted depth and only reaches maximum values, corresponding to the calculated *FC*, when this wetted depth notoriously exceeds the one of the considered layer.

Nijensohn et al. (1961) showed that "*FC* after irrigation is not reached when the depth of water applied is calculated by the method of "exact refilling" (*FC* minus moisture content before irrigation)" and these authors found that is was necessary to apply an extra depth of water over the calculated one (25 per cent more for a 0,40 cm silty loam soil layer) in order to obtain a fully avaible water storage.

The above statements make it obvious that, if there is not an unique value for *FC* which might be attributed to a given soil, depending only on its characteristics, *FC* values may vary according to the amount of infiltrated water (besides the temperature factor which in this case is irrelevant), and that the maximum water potential which reaches each one of the plots after an irrigation may also fluctuate.

In fertilizer experiments where the watering is carried out with the same periodicity in all plots and following the general practice used in the zone for the crops under trial, but without precisely controlling inflow, outflow and distribution of the water in each plot, it is highly probable that differences in stored water and its distribution will arise among the replicates. This is more evident when furrow irrigation with outlet is used. We propose the concept of *Actual Field Capacity* in order to evaluate the water actually stored, in real conditions, by a given complex soil-crop-irrigation practice.

We define the *AFC* as: *the water content of a given soil layer, in a given site, 24—48 hours after having been submitted to an irrigation of the same characteristics* (system, duration, water volume) *as those applied or to be applied in the course of the agricultural practice for a given crop.*

In a reasonably homogeneous field, irrigated with the same method and regime, differences in *AFC* may be atributed to a complex of topographic, textural, structural etc. features which are very difficult to evaluate individually, but which influence the efficiency of irrigation.

APPLICATIONS OF THE *AFC* CONCEPT

The concept of *AFC* and its utility arised first before us when we tried to find an explanation for the great yield differences between replicates, observed in furrow irrigated fertilizer experiments with tomato.

In an alluvial soil, Rodeo silty clay, with marked available phosphorus deficiency according to several diagnostic methods: lettuce technique (Jenny et al., 1950) CO_3HNa extraction (Olsen et al., 1954) and CO_2 in water extraction (Nijensohn and Pizarro, 1959), three kinds of experiments with tomato were carried out: *A*) Response to mineral fertilization (Olmos et al., 1962); *B*) Response to increasing dosis of phosphorus (Nijensohn et al., 1962) and *C*) Response to different ways of application of soluble fertilizer (NPK), (Pizarro et al., 1962). These three experiments were carried out in 4 × 4 m plots distributed in randomised blocks and with furrow irrigation with outlet. The watering took place weekly with an unique criterium for all plots as to its duration and applied water volume.

The average yields obtained showed a clear positive tendency of response to phosphorus fertilization.

However, the high experimental errors only allowed to establish statistically significative differences in the case of the N-P-K- interaction in trial *A*, as well as for the maximum phosphorus dosis (260 kg/ha) P_2O_5 in trial *B*.

Assuming the possibility that the variability between replicates, — a source of the high experimental errors —, might have been caused by differences in irrigation efficiency, provoked essentially by surface characteristics of each one of the plots, we proceeded to determine the average moisture content of the top layer of every plot 48 hours after a normal irrigation.

In this way we could verify an ample dispersion of these soil moisture values, which we denominate the *AFC* of each plot. The next step was to compare the yields of each plot against its *AFC* and to calculate the respective correlation coefficients. These proved to be highly significative in each one of the three mentioned fertilizer trials.

Figure 1 represents the scatter diagram and the regression line corresponding to experiment *C*. It is interesting to point out that the angular coefficient of the regression equation corresponding to this trial was practically equal to the one calculated for trial *B*. The above statements show that the *AFC* influenced the yields independently of the fertilizer treatments, including the blank one. The full expression of the positive effect of the fertilizers could only be revealed in cases when *AFC* values were near the same as the *FC* ones.

A very detailed altimetric survey was carried out, plot by plot, in trial *B*. This survey showed the following suggestive facts: while the five plots with the best yield — independently of fertilizer treatments — had an average slope of 0.74 per cent, the five plots with the worst yield had an average slope of 1.12 per cent.

The general influence of the *AFC* upon the tomato fruit production having been demonstrated, we hypothesized that the different yields obtained in the replicates were a direct consequence of the different average *AFC* (during the whole course of the experiments) of the respective plots. In accordance with this point of view, and the *AFC* being independent of the treatments under trial, homogeneous blocks, as to edaphic characte-

ristics, would be those which are composed of plots with equal or very similar *AFC* values. It is improbable for such a condition to exist in randomized blocks, the way they ordinariy are layed out in fertilizer experiments; in the reported trials they proved to be highly heterogeneous in relation to

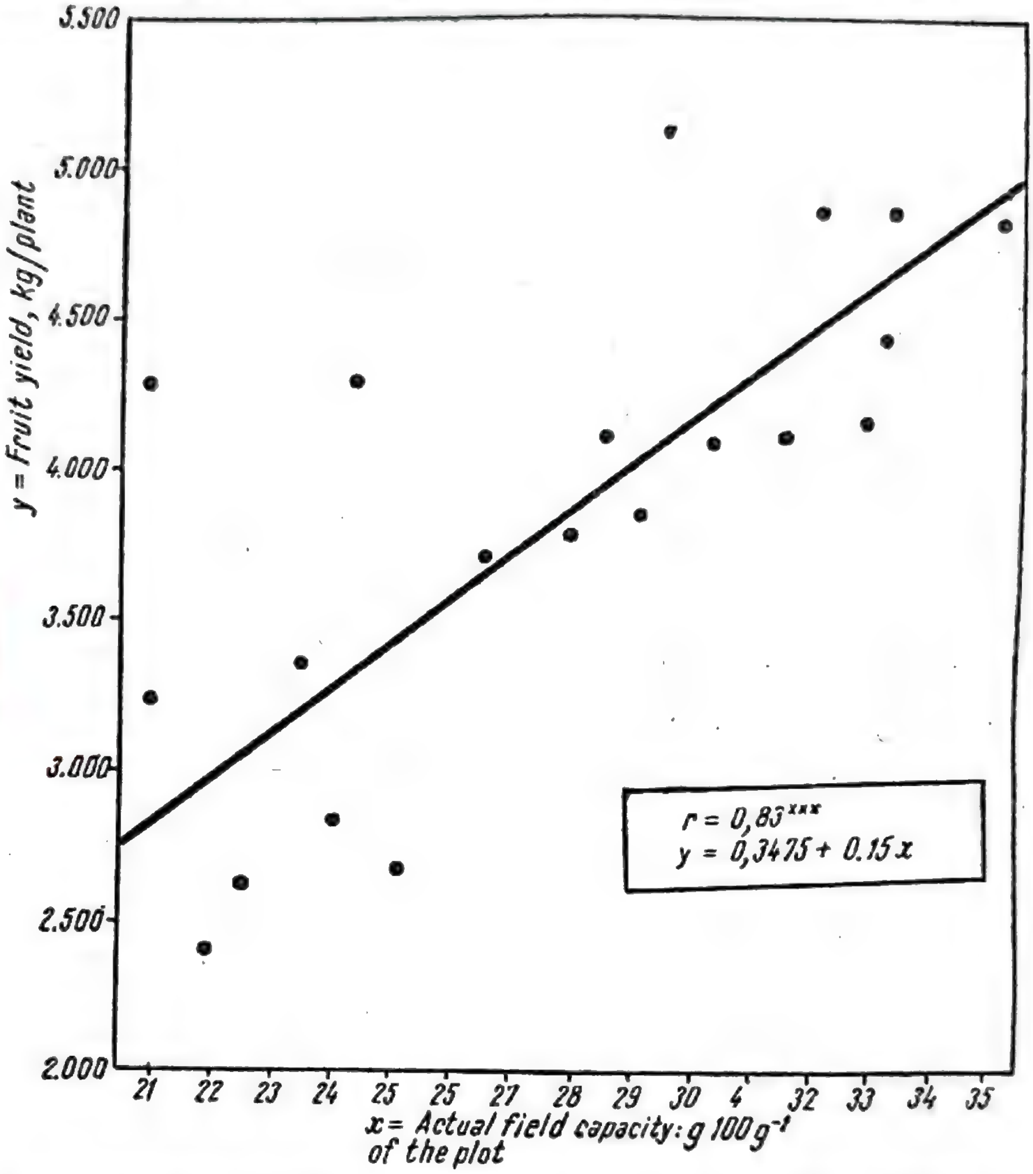

Fig. 1. Correlation between yield and actual field capacity: tomato response to different ways of application of soluble fertilizer in Rodeo silty clay.

the *AFC* factor. We tried to study the influence that a higher homogeneity of the blocks could have had upon the statistical significance of the average yields obtained in the above trials. The method to demonstrate this was to rearrange the blocks in such a manner as to include in each one of them the replicates of the same order in the increasing yield series established for each one of the assayed treatments. This done, we repeated the analysis

of variance with the same experimental results but distributed in the new rearranged hypothetical blocks.

In this way it was shown that the least significant difference to distinguish yield averages between treatments diminshed in the experiment *A* from $\pm$ 1.089 kg/plant to $\pm$ 0.470 kg/plant, and in the experiment *C* from $\pm$ 1.148 kg/plant to $\pm$ 0.349 kg/plant. That is to say: if the *AFC* values of each plot were taken into account in the laying out of the blocks, a considerably smaller experimental error would be attained.

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SUMMARY

The possibility that slight differences in microrelief and/or in infiltration rate may be the cause of variations in the water storage capacity, even in plots of apparently homogeneous soil under the same irrigation practice, is reported.

In order to define the upper available water content for a given site (plot) under a given irrigation practice, the concept of Actual Field Capacity (*AFC*) is proposed.

The possibility of a diminution of the experimental error in fertilizer irrigated experiments through taking into account *AFC* plot values in the laying out of the blocks is pointed out to and discussed.

RÉSUMÉ

Dans ce travail on rapporte la possibilité que les petites différences de microrelief et/ou de la vitesse d'infiltration soient les causes des variations dans la capacité de rétention de l'eau du sol, même dans les cas des parcelles d'un terrain apparemment homogène et soumis à la même pratique d'irrigation.

Pour définir la teneur maxima en eau disponible atteinte par une certaine couche édaphique, pour une parcelle déterminée et soumise à une pratique d'arrosage donnée, on propose le concept de la Capacité Réelle au Champ (*CRCh*).

On signale et on discute la possibilité de diminuer l'erreur expérimentale dans les essais à engrais en sols irrigués, au moyen de la détermination de la *CRCh* de chaque parcelle et sa considération dans la répartition des blocs sur le terrain d'expérience.

ZUSAMMENFASSUNG

Es wird über die Möglichkeit berichtet, dass kleine Mikrorelief-und/oder Infiltrationsgrad-Unterschiede die Ursache von Variationem im Wasserspeicherungsvermögen, auch in Versuchsfeldern mit anscheinend homogenem Boden unter einheitlicher Bewässerung, seien. Man schlägt den Begriff „Aktuelle Feldkapazität" (*AFK*) vor, um den höchsten Wert des verfügbaren Bodenwassers (nutzbare Kapazität) eines Standortes (Parzelle) unter bestimmter Bewässerung zu bezeichnen.

Ferner wird die Möglichkeit einer Verringerung des Experimental-Fehlers in der Versuchsordnung bei Düngungs-Experimenten in bewässerten Böden durch Beachtung der *AFK*-Werte der Versuchsparzellen angedeutet und erötert.

DISCUSSION

A. FEODOROFF (France). I should like to know if the *AFC* depends on the quantity of water supplied by the previous irrigation.

L. NIJENSOHN. The *AFC* depends primarily on the amount of water infiltrated in the given site, and this is related to the microrelief and physical conditions of the soil surface.

DROP IRRIGATION SYSTEM

PIETRO CELESTRE[1]

1. INTRODUCTION

The technology of irrigation is surely a determining factor in soil physics and in plant nutrition. An entirely new technique in irrigation is now possible and therefore it is presented to this Congress for a more complete examination among soil scientists[2].

The existing irrigation methods can be divided into two categories or systems on the basis of the distribution of water in time and space. The first category comprises flooding and spraying (or sprinkling) methods and it is characterized by the application of water to land with full continuity on the surface, but long discontinuity in time; the second comprises furrow and sub-irrigation methods and it has partial continuity on the surface and yet a long discontinuity in time.

The present methods constitute a third category or system, characterized by partial continuity (not worse than above) in the soil surface and full continuity in time. These methods have been recently proposed (Celestre, 1960, 1964) and they appear more profitable from the agronomical and economical point of view.

The absence of permanent irrigation in the past centuries can be considered to have been caused by a technological insufficiency; anyway its absence is surprising in the last decades in view of the huge and cheap availability of plastic materials.

The new system changes radically the character of irrigation and it raises entirely new problems in soil physics, chemistry and biology. At present these problems can only be initiated.

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[2] A communication on "Drop irrigation" will be held also at the "VIth Congress Génie Rural — Laussanne — Sept. 1964" where the technical and economical sides will be stressed, while here the soil inferences are presented.

2. DESCRIPTION OF THE SYSTEM

The system introduces different ways of application of water to land, based on a permanent or almost permanent watering. Therefore it changes entirely the final part of an irrigation work, while the initial part (main canals or pipes, structures etc.) remains unaltered. Besides, the continuity in watering determines the steadiness of the flow in the distribution network and the reduction of the discharges to exigous values. In conclusion one may distinguish the three following parts in the suggested irrigation work:

I. main canals or pipes, intakes etc., *the same as in traditional works*;

II. distribution network in canals or pipes *similar to traditional, but much reduced in size*;

III. irrigating equipments, *substantially different from the traditional ones*.

The descriptions and discussions, shall of course, regard mostly part III; anyway a particular attention has to be paid also to the quantitative modifications of part II, which introduces the principal reductions in the total installation cost.

The continuity of irrigation should be intended as a quality of the system not as a reality; in other words the permanent irrigation is possible but not necessary. During rains or during humid periods, of course, interruptions of service are necessary in a distribution network proportioned to the more consuming period. Besides, some regular intermittences can be useful and introduced by purpose.

The discharges are reduced in accordance to the chosen degree of continuity. The rates between the discharge Q in a conventional irrigation and that q in the corresponding present method are

$$q = \frac{h}{24\ n} Q \text{ for full day continuity,}$$

$$q = \frac{h}{16\ n} Q \text{ for 2/3 day continuity,} \tag{1}$$

$$q = \frac{h}{12\ n} Q \text{ for 1/2 day continuity,}$$

where: h — hours of application, n — time in days between irrigations. For instance, in case of h — 1 hour, n — 10 days, the rates are respectively

$$q = 0{,}004\ Q,$$

$$q = 0{,}006\ Q,$$

$$q = 0{,}008\ Q.$$

Usually the terminal discharges (or "water duty") are reduced at the rate of 1/100—1/1,000.

The system has been achieved in practice according to several solutions or methods, while many others appear possible. In any case we have distin-

guished four general methods: shared type, localized type, accumulated and spread type, accumulated and sprinkled type. For more details on these methods one may consult two previous papers (Celestre, 1960, 1964).

A. *Drop shared irrigation*

The water is distributed uniformely and continually over the full surface of the land. The equipment comprises.:

a) a *capillary net* of plastic pipes, supplying the water to land through holes or other devices, as exemplified in figure 1. The capillary pipes derived from the final ditch or pipe either single or in groups of two or three;

b) an *insertion* at the inlet of the capillary pipe to check the flow and to regularise it (Celestre, 1960).

The land requires no levelling or other careful preparation; in steep slopes it is sufficient to lay the capillary pipes along the level lines. The network is laid down seasonally or for a longer time; in any case it can be easily removed when farm works require it. The system (fig. 2) appears already applicable to intensive or special crops such as horti- or floriculture, yet it is intended to be tried also for extensive crops.

The solution with buried (fig. 1 *e*) or alternatively buried pipes (fig. 1 *a*, *b*, *c*,), is distinguished from sub-irrigation by two fundamental aspects: the pipe is laid usually at a few inch es ($1 \div 20$) and temporarily rather than ever deep and permanent; the flow is daily or part-daily steady and very low while the sub-irrigating pipe has isolated and peak flow.

In our trials the buried pipes proved more convenient concerning the uniformity of the dropping sand evidently the reduction of the evaporation.

B. *Drop localized irrigation*

For certain crops a partial watering of the land is sufficient; usually watering is limited to some spots or stripes of the agricultural surface, instead of beeing shared over the full plane. The first situation is typical in arboriculture, the second in horticulture.

The method (fig. 3) substantially repeats the preceeding one, and is distinguished by the following parts:

— the spacing of the pipe and the percolation points are usually larger;

— the dropping devices change in form or at least in size;

— for tree cultivations often the dropping device can be an appendix plunged into the earth and operating a hypodermic transfusion.

The drop system displays the more economical advantages the more confined the watered portions are. More advantages are revealed by the confinement in time, as is in the case of orchards. Fruit irrigation is often limited to low and sporadic, but timely, applications of water. It needs, with the usual methods, a fixed pipe-network, widely sized and seldom operated, but numerous and urgent labourers for a ready watering in the special seasons. The present method, instead, because of its slender capillary-network and because of its natural automaticity, reduces the first cost and cancels the second.

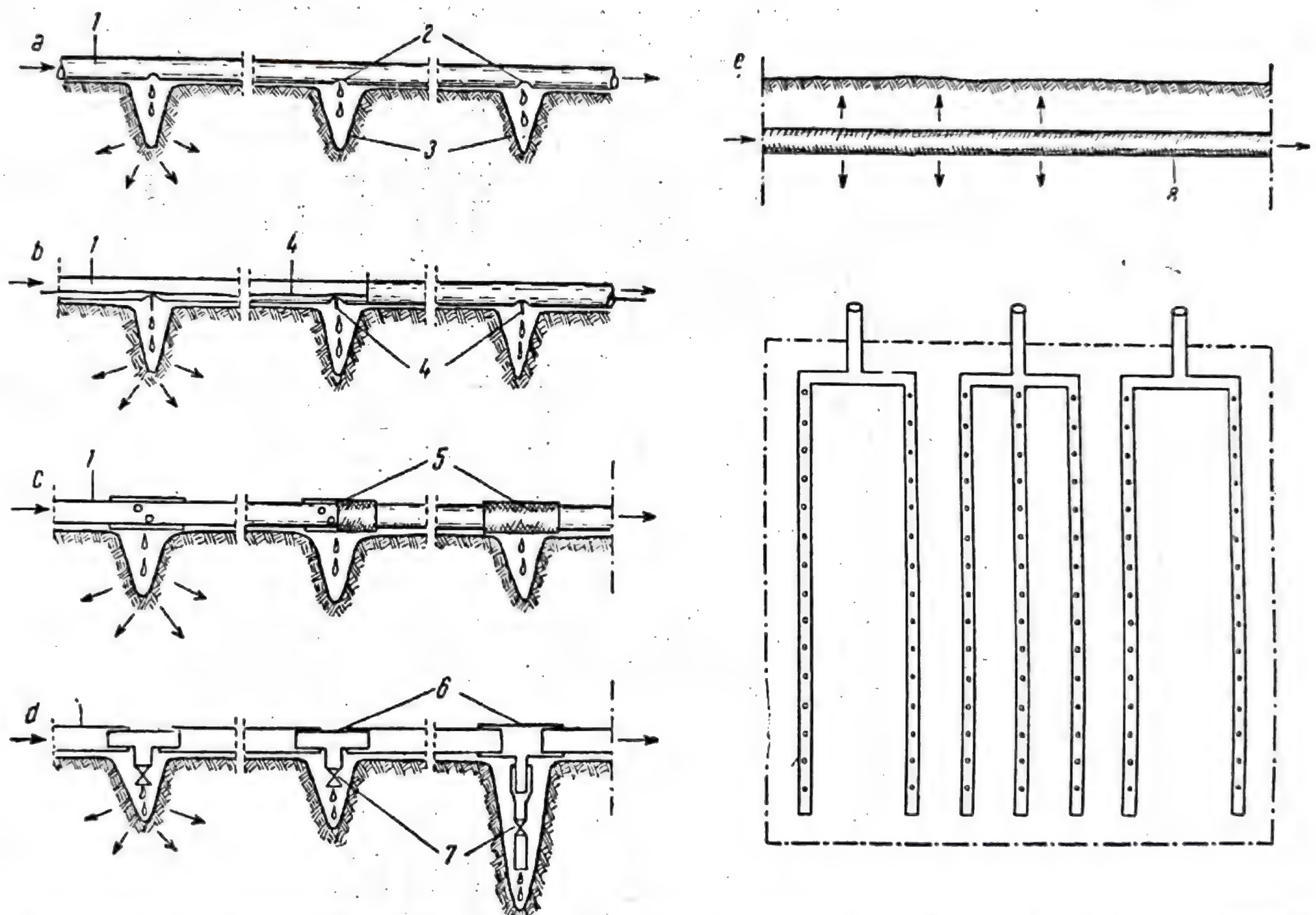


Fig. 1. Schemes for the drop shared irrigation method: *1*—plastic or rubber pipe; *2*—holes with 0,5—2 mm diameter (preferably not alinged); *3*—indentations into the earth (generally made with a trowel; they are optional); wick (fixed individually or descending from a continuous wire); *5*—sleeve; *6*—metal or plastic fitting (joined internally-externally); *7*—clamps; *8* — permeating pipe. — Schema *a*, *b*, *c*, *d* can alternatively be buried; schema *e* can be in open air.

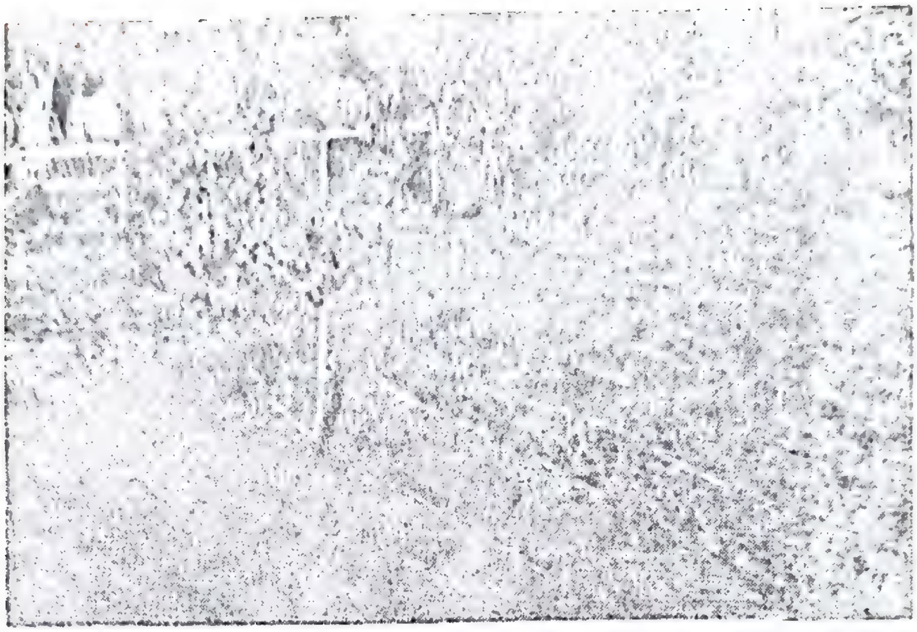


Fig. 2. Application of the shared method.

Fig. 3. Application of the localized method.

To control the local watering of the plunged appendix it is helpful to add a transparent expansion, just like in surgery for hypodermic transfusion. Every month it is convenient to change the point pierced near the plant.

C. *Drop accumulated and spread irrigation*

This method differs in the fact that the permanent flow of water arriving to the field (or to a parcel of the field) is accumulated in a little vessel (usually 50—300 l) and is transformed into a higher discharge, capable of furrow or flooding irrigation.

The vessels fill slowly, during a time t, with the arriving discharge q and, when full, they empty automatically and quickly, during a time T, producind the departing discharge Q. Figure 4 shows the hydrograph of the levels $H(\theta)$ in the tank in function of the time variable θ. The flows q, Q and times t, T correspond evidently through.

$$Q = q(1 + t/T) \tag{2}$$

accepting that $Q \simeq$ const.

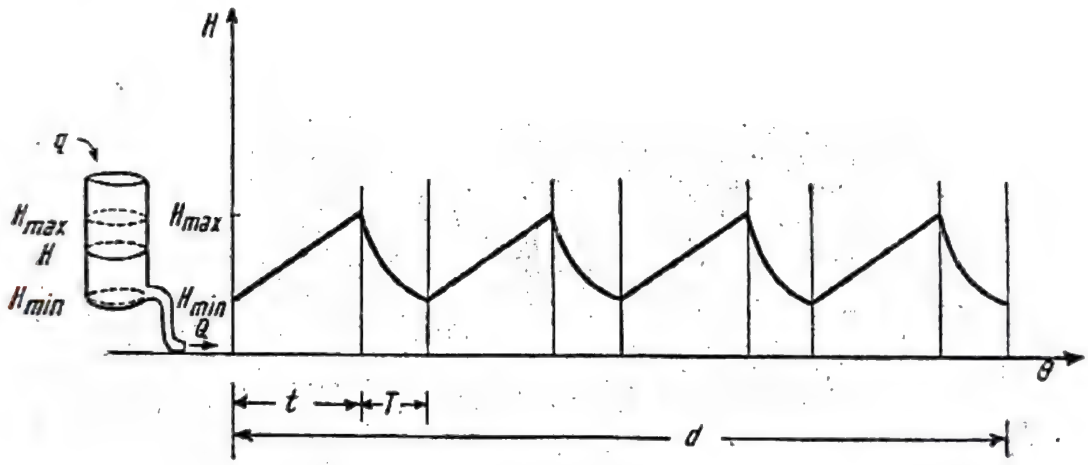


Fig. 4. Variation of the tank level H versus time θ.

The automatisms for the tank emptying have been cared for so as to assure the utmost simplicity and safety. A single siphon is not sufficient, because the flow q is weak and unable of producing self suction. Mechanical devices have been avoided as fastidious and wearing. Five automatisms have been chosen, which permit low expenses and safe functioning; they are illustrated in previous papers (Celestre, 1960, 1964).

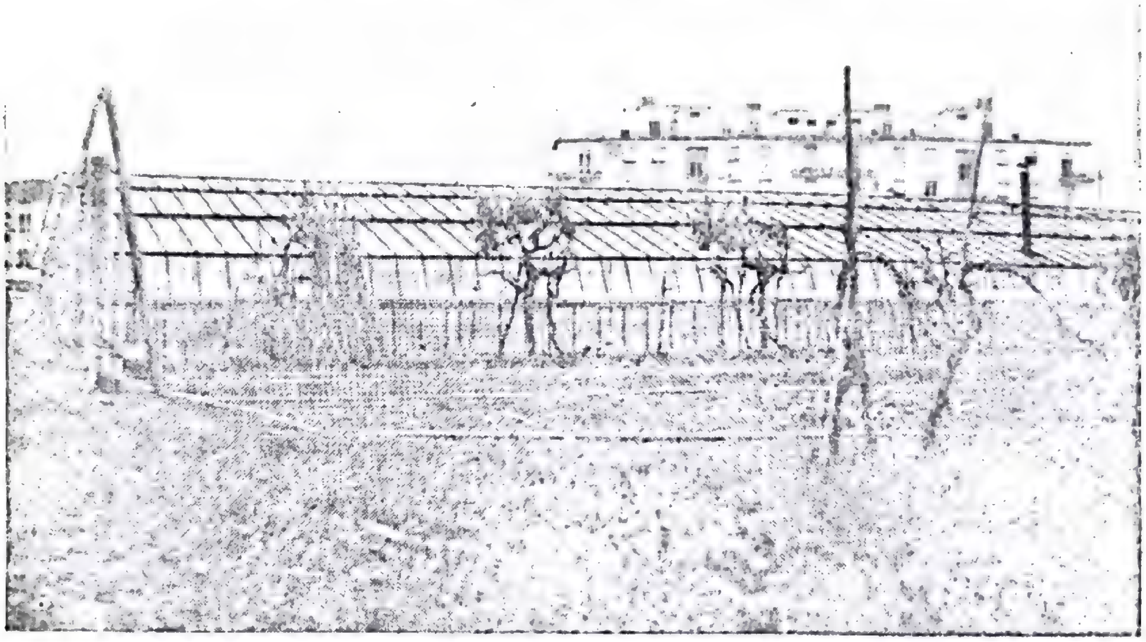
The form of the vessel is almost free; it is preferable to have one with a large base and a small height. The watering has been realised by distributing the flow to furrows through a pliant pipe "plastocanale Pirelli" and flooding the furrows, barred with earth at regular intervals (fig. 5). Usual furrow irrigation or other spreading irrigations can also be achieved.

Fig. 5. Application of the accumulated and spread method: *upper figure* — general sight; *lower figure* — regulating device.

D. *Drop accumulated and sprinkled irrigation*

The application of water to land is performed following a similar accumulation of the continuous supply q and employing bored pipes for eeding sprinkling (fig. 6).

This method can use automatic devices, for emptying the storage vessel, similar to those of the precedent method; anyway, some devices are



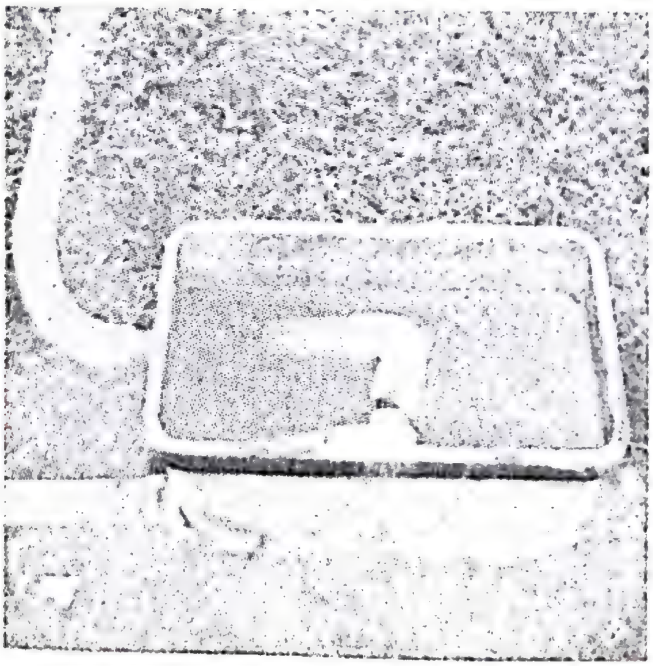


Fig. 6. Application of the accumulated and sprinkled method: *upper figure* — general sight; *lower figure* — regulating device.

fiter for the first kind, some for the second. Then the vessel has to be of a particular form and height: the higher the level of the stored water, the longer is the throw of each jet.

The method introduces the noticeable advantage of achieving a more uniform water application than by the conventional methods, including

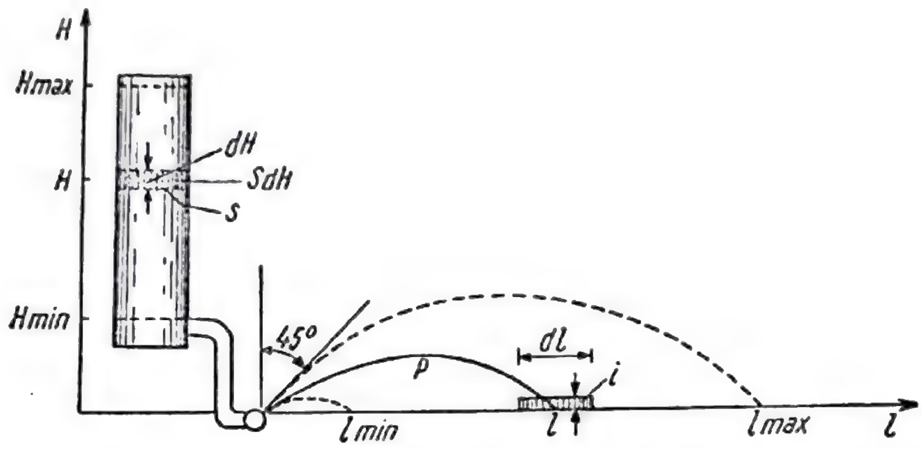


Fig. 7. Volumetric balance between tank level and jet flow (explanations in the text).

the usual bored-pipe sprinkling. Uniformity is now ensured according to laws of a jet under variable heads $H(\theta)$, after which its efflux p and its throw l are:

$$p \, d\theta = S \, dH \qquad l = 2H$$

(S = section area of the vessel) so that the rate between p and the velocity of watering $dl/d\theta$ results constant

$$\frac{p}{dl/d\theta} = \frac{S \, dH/d\theta}{2 \, dH/d\theta} = \frac{S}{2} = \text{const}$$

with the condition that S = const, i.e. that the vessel is cylindrical (fig. 7);

This method needs no levelling of the land; only it is convenient that the bore pipes lay on level lines. Figure 6 shows an experimental application.

The four practical methods, illustrated above, require adequate design only for the watering equipments (part III of the work). This design is simple, anyway it escapes from the scope of this presentation. The design of the distribution network (part II of the work) can yet be performed with the usual formulas, now with the advantages that the flow is entirely steady in all the network and that the final pipes have often laminar flow and therefore an almost insignificant energy loss and equal outflows.

3. DISCUSSION AND PRELIMINARY RESULTS

The experimental examination of the new system is still scarce due to a complete lack of funds and to a surprising incomprehension during the past years by the National Research Council of Italy, of which the financial support depends.

The hydraulic behaviour of the four methods has more easily received examination and it can be considered entirely satisfactory. Many improvements can surely be made; anyway the major problem is technological: proper quality of material and accuracy in manufacturing.

The effects of the new methods on soil properties and on plant growth open a wide program of researches, which in any case can only be started. The usual literature cannot furnish informations about a permanent irrigation, as such a field was neglected.

The "irrigation efficiency" (the ratio of the volume of utilized water to the volume of distributed water) is undoubltedly higher in the new methods than in the traditional ones.

A first efficiency (the ratio of soil retained water to the distributed water) has been measured comparing 5 types of soil watering: 1 — sudden pouring on the surface, 2 — dropping on surface, 3 — dropping at a 10 cm depth, 4 — dropping at a 30 cm depth, 5 — dropping at a 60 cm depth. The tests, though imperfect and depending upon several occasional variables (soil nature, season etc.) can anyway be considered indicative and they show the figures in table 1.

Table 1

Water retained by the soil (per cent from water distributed) for 5 methods of watering

Method of watering		Days after watering			
		5	10	15	20
pouring at surface		70	64	60	56
drop irrigation	at surface	82	82	80	78
	at 10 cm depth	92	90	90	89
	at 30 cm depth	96	95	93	90
	at 60 cm depth	90	87	85	82

The higher efficiency in water application of cases 2, 3, 4 can be attributed to lower losses in evaporation and in deep percolation. Another factor, which appears the application efficiency, is the fact that drop irrigation displays a fairly uniform diagram of water distribution all over the field, while furrow irrigation has usually a decreasing wetting diagram along the furrow length and the sprinklers exceptionally have uniform rain diagrams (or at least these diagrams are modified by soft winds).

A second efficiency (the ratio of water consumed by plants to water retained by the soil) is surely higher in drop irrigation than in the usual ones, because the moisture can now be kept at the wanted degree, while before it had a forced passage from saturation to wilting aridity. The utilisation efficiency is more important than the preceeding application efficiency; its evaluation is not easy as it varies with several factors (plant kind, soil nature, moisture degree, fertilizer, tillage, climate etc.) and as the measures of evapotranspiration are delicate. Some possible tests are in course also in this large field.

The diffusion of water in the soil represents a preliminary and fundamental examination, about which it is possible to give some results sufficient at least as indications.

In a clay soil the diffusion has proved fairly steady and fast; the diagrams of figure 8 show the diffusions versus time for 4 levels of the drop input.

The temperature and the aeration of the soil evidently undergo sensible differences with drop irrigation. Presently we must limit ourselves only to a few observations. As for temperature, the waters assume now the air temperature because of the long and capillary distribution pipes; the damages often produced by cold waters from a deep well are now avoided; reversily the advantage of refreshing with water the land surface in hot climates is now impossible. A refreshment could anyway be produced using the third and fourth method of drop irrigation, taking advantage of the evaporation. The refreshment should be lower than in furrow or border irrigation but available for a longer time and during all the days wanted.

As for the aeration, here again data are not available; anyway in every soil samples digged out for moisture measurements it was evident that pores were not water logged and that aeration was entirely possible.

Night service of drop irrigation saves in evaporation and gains in dew condensation. The thermic balance of ground, transported water and air humidity raises an interesting problem. Soil erosion, often occuring in usual irrigations, is entirely avoided by the four present methods.

The influence of the proposed irrigation on plant nutrition represents naturally the main problem. As a general and main result it can already be stated that plant growth is more favoured by drop irrigation than by other methods. A first and personal proof can be found in the farmers' own experience, by which at equal duty of applied water small and frequent irrigations are more useful than peak and rare irrigations. Lands being permanently supplied by rich aquifers or by near rivers have luxuriant vegetations. Oases are a fair example of the benefit of a permanent undergound supply in hot climates. Trials about this basic aspect are naturally in course and mostly in program.

In the above paragraphs it has been possible to give only some preliminary hints regarding soil physics. This section is the more urgent but also the easier. The influences of the proposed irrigation on the chemical and biological conditions of the soil and of the plant raises far wider and harder problems. In such an important section the contributions, controls and cri-

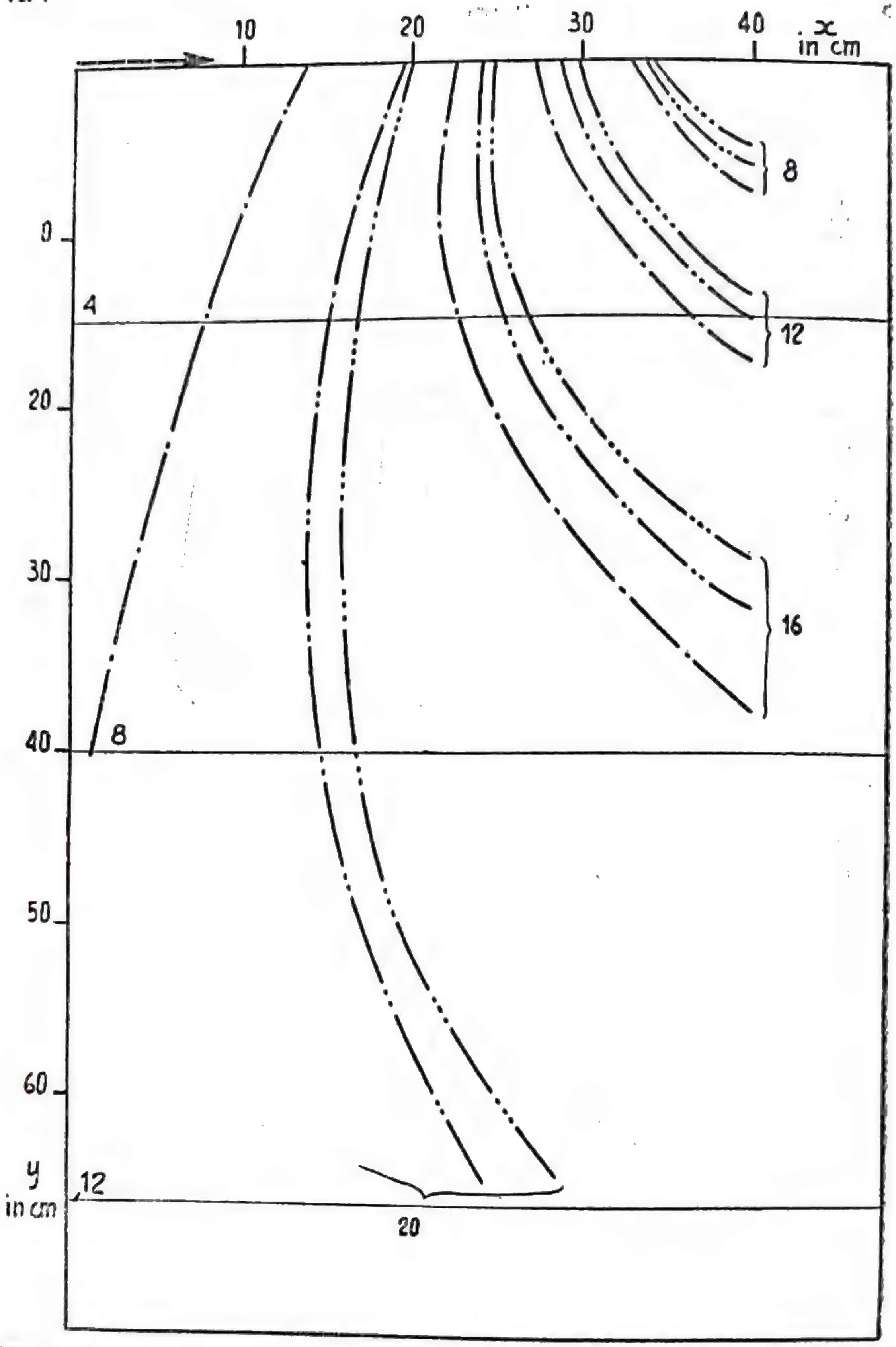


Fig. 8. Moisture diffusion in the ground during 16 days and for 4 points of the water input (rate 7 *l/day*) ; *a* — water input at soil surface. The arrows show the point of the water input. The figures within the graphs (*4, 8, 12, 16, 20*) represent moisture contents (% of moist soil weight).The curves within the graphs represent lines of equal moisture content for the initial day (—) and for *4* (— . —), *8* (— ..—)and *16* (— ...—) days after the water input.

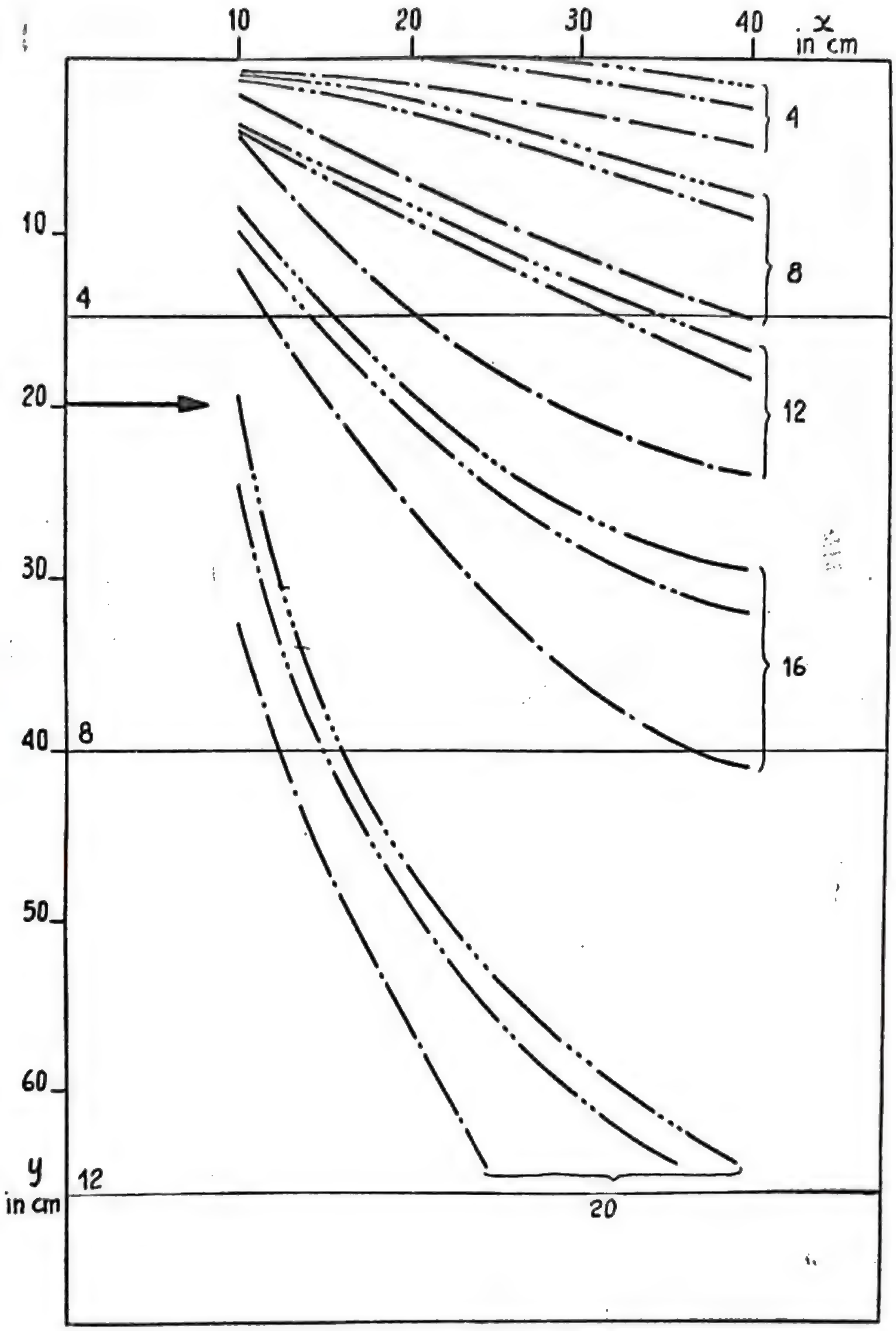


Fig. 8. *b* — water input at 20 cm depth;

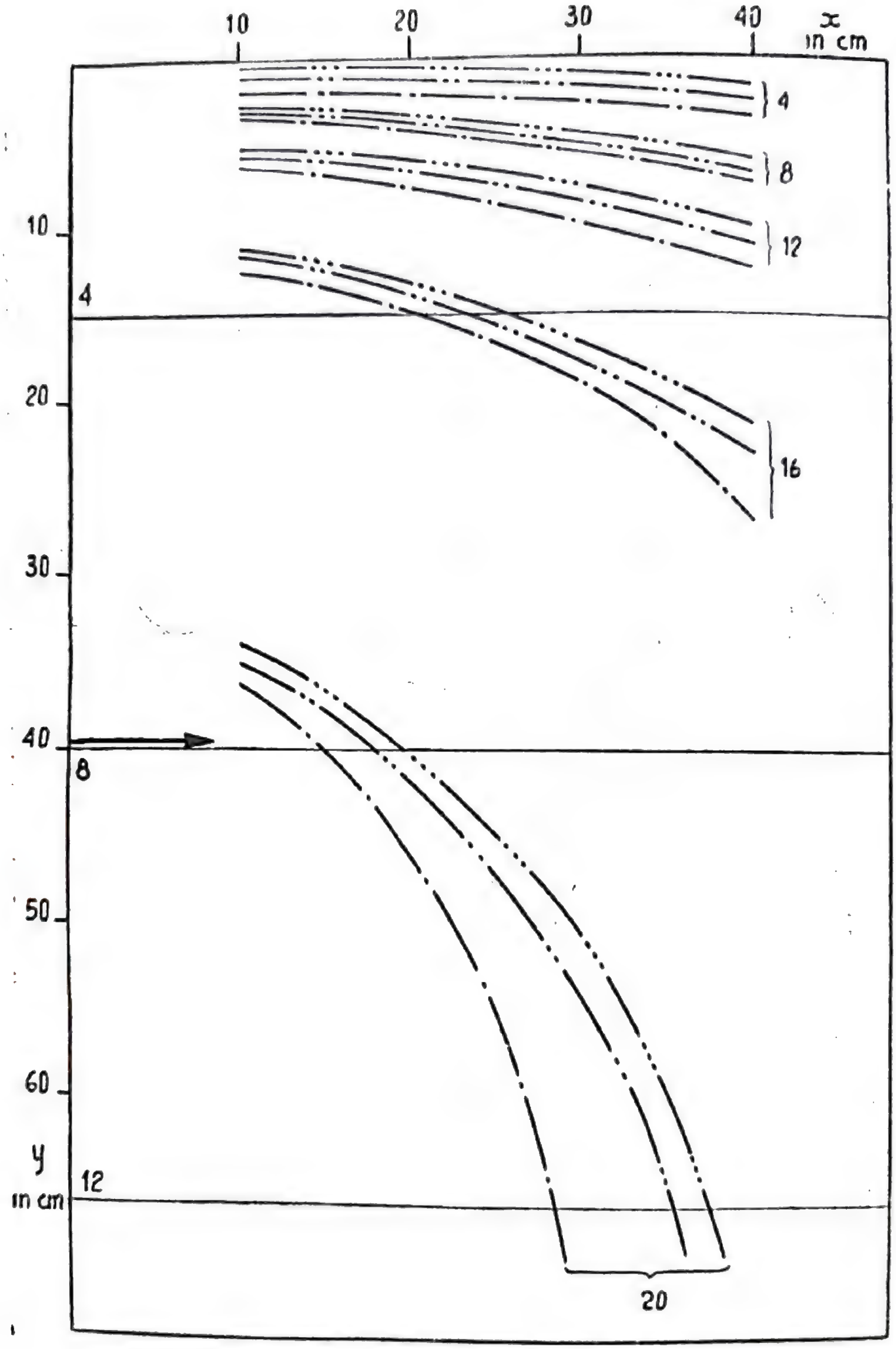


Fig. 8. c — water input at 40 cm depth;

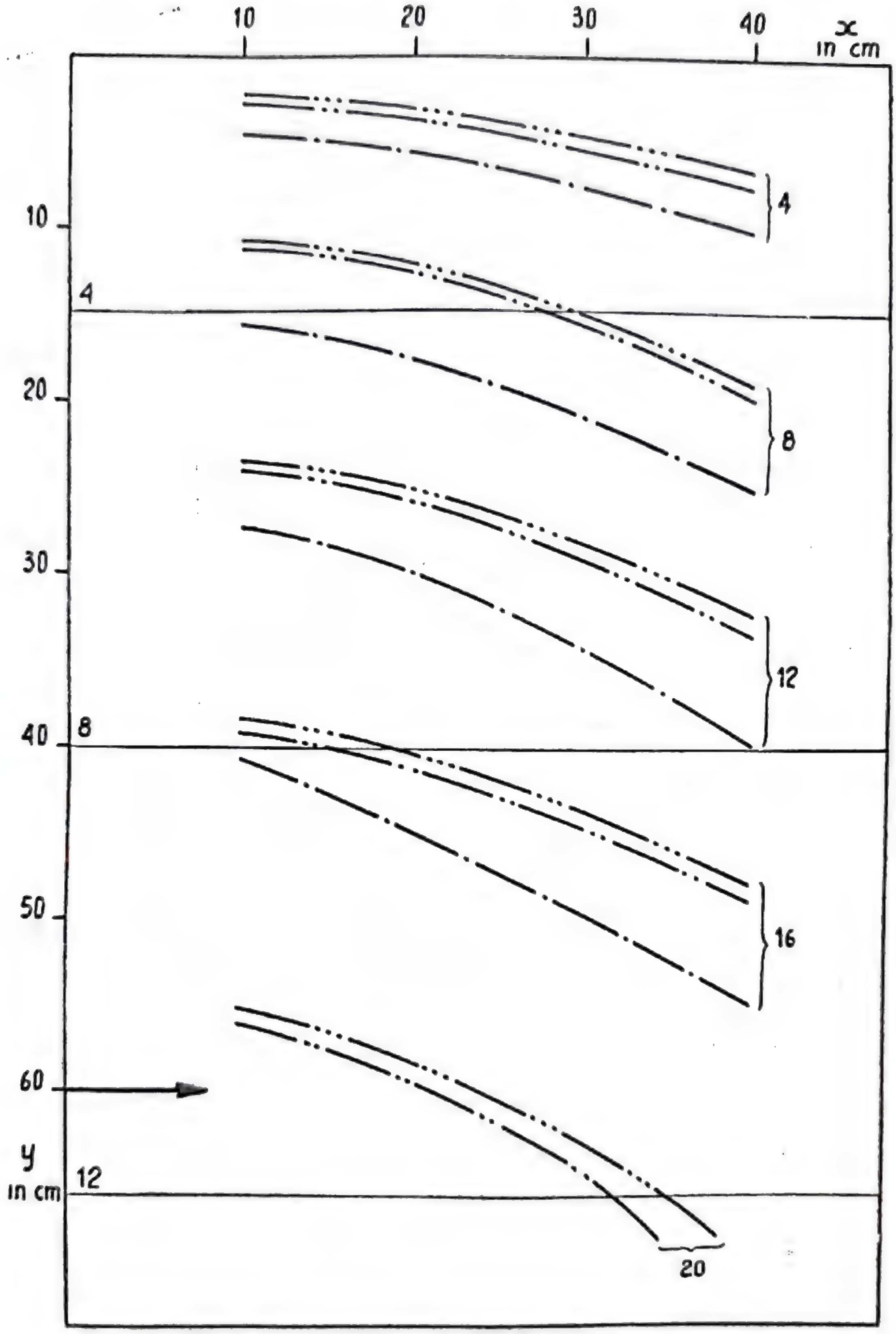


Fig. 8. *d* — water input at 60 cm depth.

ticisms of other researchers are useful and — I believe — necessary. Besides the economical difficulties encountered, this fact constitutes another reason for the presentation of the proposed irrigation to soil scientists.

4. CONCLUSION

Though many examinations and improvements are still necessary, the drop irrigation can already be considered very satisfactory from every point of view.

The hydraulic functionality is ensured by all four methods; the shared method appears the more delicate for getting uniform droppings.

The agronomical side remains still unexperienced and uncertain. Anyway the new system affords two remarkable advantages which opens safe doors: the first advantage is the possibility to adapt day by day the supplies of water to the requirements of the plant and the second is the easiness of irrigating timely in any part of the farm during the critical vegetation periods.

The economical side, too, appears favourable. The effective cost of the new methods depends much of the possible technical improvements and of a large industrial production. The economical balance must be formed by three costs: installation of the fixed distribution network (part II of the work), installation of the mobile watering equipments (part III of the work), labour. This first cost is strongly reduced in proportion to the small ration q/Q of the present and usual discharges (see (2)). The second cost is higher than the corresponding costs (ground levelling, furrows, ditches, etc. for furrow or border irrigations; sprinklers, portable-pipes, valves etc. for sprinkling irrigation). The third cost, labour, is practically cancelled as the watering becomes automatic and ast he man service is reduced to operation of the valves of the pipe network and to occasional inspections to the watering equipments. In all the balance is in favour of the drop system. An indirect confirmation of this conclusion is given by the modern trend to develop automatic plants with rather complicated moving irrigators or with electric or hydroautomations and to install as many fixed pipes as possible.

Other advantages which encrease the economy of the drop system are:

The flow in pipes and the land watering are possible at the lowest pressures; in practice pressures coresponding to the ground elevations, increased by 1 m or about, it are sufficient. It represents an important saving, in comparison with the high heads, necessary for usual sprinklers, which cause heavy pumping costs and expensive pipe walls.

The automation of irrigations is already achieved, the flow being steady and its regulation being simple through main valves. The system, besides, is already superior as readiness and simplicity to the known irrigation "à la demande".

The dropping pipes, laid on the field at more or less large distances by this method, disturb undoubtedly the farm works. Anyway such pipes are slender or at least pliable, so that they can be easily removed and even-

tually stored. This network is semi-fixed (seasonally or monthly fixed, or similarly) and the expense for its deplacement is not sensible.

A fifth method already under study and very successful is drop irrigation with accumulation in autoclave tanks.

Modern farming becomes continually more organized and mechanised; the favorable properties of the drop system, and in particular the elimination of labour, allow to foresee that in a near future the irrigation will be confined to solutions as indicated above.

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SUMMARY

A new system of irrigation, based on a permanent or semi-permanent watering is reported, and several of its influences on soil physics and on plant nutrition are presented. The system consists of four practical methods, named: shared; localized; accumulated and spread; accumulated and sprinkled. The main advantages are: possibility to follow the daily water requirements of the plants, steady flow in the distribution network and reduction of the discharges to rates 1/100—1/1,000, similar or smaller total cost of the work in comparison with the traditional system, automation of the watering and elimination of labour.

RÉSUMÉ

On présente un rapport sur un nouveau système d'irrigation, basé sur un arrosage permanent ou semi-permanent, et l'examen de plusieurs de ses effets sur la physique du sol et sur la nutrition des plantes. Le système offre quatre méthodes fondamentales et plusieurs variétés pratiques qui ont été appelées: méthode répartie, localisée, accumulée et déversée, accumulée et arrosée. Les principaux avantages sont: possibilité de suivre les besoins journaliers en eau des plantes, écoulement permanente dans le réseau de distribution de l'eau et réduction des débits au degré 1/100—1/1 000, dépense similaire ou inférieure du nouvel aménagement par rapport aux aménagements traditionnels, automatisme de l'arrosage et élimination de la main-d'œuvre.

USAMMENFASSUNG

Es wird Bericht dargelegt, über ein neues Bewässerungssystem, gegründet auf eine ständige und halbständige Bewässerung und eine Prüfung ihrer verschiedenen Einflüsse auf die Bodenphysik und auf die Ernährung der Pflanzen. Das System weist vier praktische Methoden auf, folgendermassen benannt: verteilte, lokalisierte, zusammengehäufte und verbeitete, zusammengehäufte und besprengte.

Die Hauptvorteile sind: die Möglichkeit den täglichen Wasserbedarf der Pflanzen zu verfolgen, ständiges Einströmen in das Verteilungsnetz des Wassers und Herabsetzung der Durchflussmenge auf 1/100—1/1000, ähnlicher oder geringerer Kostenaufwand für die neue Anlage im Vergleich zur herkömmlichen, Automatisierung der Bewässerung und Wegfall der Arbeitskraft.

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IRRIGATION DEVELOPMENT IN THE WESTERN UNITED STATES AS RELATED TO THE GREAT SOIL GROUPS

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INTRODUCTION

Irrigation development in the Western United States occurs on a large portion of the set of Great Soil Groups as defined in the American system of soil classification (Baldwin, Kellogg and Thorp, 1938). Included are Northern Chernozem, Southern Chernozem, Northern Dark Brown (Chestnut), Prairie, Brown, Non-calcic Brown, Northern Sierozem and Desert, Southern Sierozem and Desert, Gray-Brown Podzolic, Red and Yellow, Alluvial, Rendzina, and Planosol. In addition reclaimed areas of Solonetz and Solonchak are under irrigation. Through the years of agricultural development and its adjustment to a highly competitive economy, broad regionalized patterns of farming types have become discernible (Highsmith, Jensen and Rudd, 1962). In the conterminous United States, 165 types of farming areas have been recognized showing a wide diversification of agricultural production (United States Department of Agriculture and United States Department, U. S. Census of Agriculture, Vol. V, 1959). On irrigated land in the Western United States a recent study by the Bureau of Reclamation, identifies about 48 types of irrigation farming areas across the subset of irrigated Great Soil Groups.

INTERACTION PRINCIPLE

The patterns of irrigation farm types and associated enterprises express interactions of climatic, land, economic, and social factors operating over time. This principle expresses a dynamic concept. While climate may be regarded as stable over historic periods, all other factors are subject to change. Thus shifts in use and productivity of resources are continually occurring which alter the irrigation farm type patterns... including both composition and distribution of the patterns. Outstanding examples are the shift of cotton westward onto irrigated land, increases in hay and feed crops, increase

Bureau of Reclamation, Interior Department, Washington, U.S.A.

in livestock numbers, increases in cash crops as lands inadequately irrigated are provided a full water supply, and emergence of important alfalfa seed producing centers on irrigated lands in California and Washington.

Climatic and Land Factors

The physical factors of climate and land exert a primary controlling influence over the patterns. This may be derived from the tolerance theory of Good (1953) a portion of which states: "Each and every plant species is able to exist and reproduce successfully only within a definite range of climatic and edaphic conditions. This range represents the tolerance of the species to external conditions" (Here it should be recognized that pattern changes may occur as a result of plant breeding... such as the development of early maturing or salt tolerant crop varieties).

Primarily then the external physical conditions determine the outside limitations of what will or will not grow. This range of tolerance is graphically depicted in figure 1.

It is generally recognized that climates tend to remain relatively uniform over wide areas and that similar climates are repeated throughout the world on the land masses in characteristic latitudinal and continental locations. Since these climates are correlated with general and repeated patterns of soil (Blumenstock and Thornthwaite, 1941) a general regionalized association of the Great Soil Groups with irrigated agriculture can be expected. This relationship between climate and soil is graphically depicted in figure 2. Irrigation alters the moisture supply and thereby profoundly

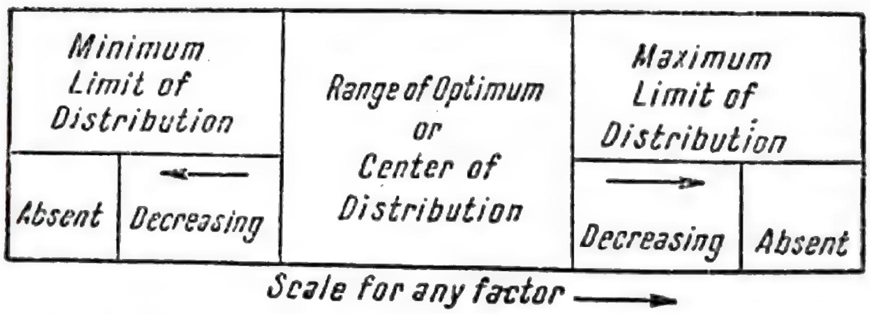

Fig. 1. Ecological concept of the range of tolerance (Shelford, 1913).

changes the capacity of a soil to produce crops. This effect, in terms of regional patterns, results in climatic factors overshadowing the influence of soils under irrigated crop production.

As a phase of broader investigations into the relationship of climate and land to irrigation productivity, studies were conducted to measure the degree of association between a subset of the Great Soil Groups and the gross

value of crops produced within each Group. A sample of 89 observations were drawn from Bureau of Reclamation irrigation projects located on the southern Desert, Northern Desert, Northern Brown, Northern Dark Brown (Chestnut), Northern Chernozem, and Southern Chernozem Great Soil Groups. Each sample represented optimum conditions for production under irriga-

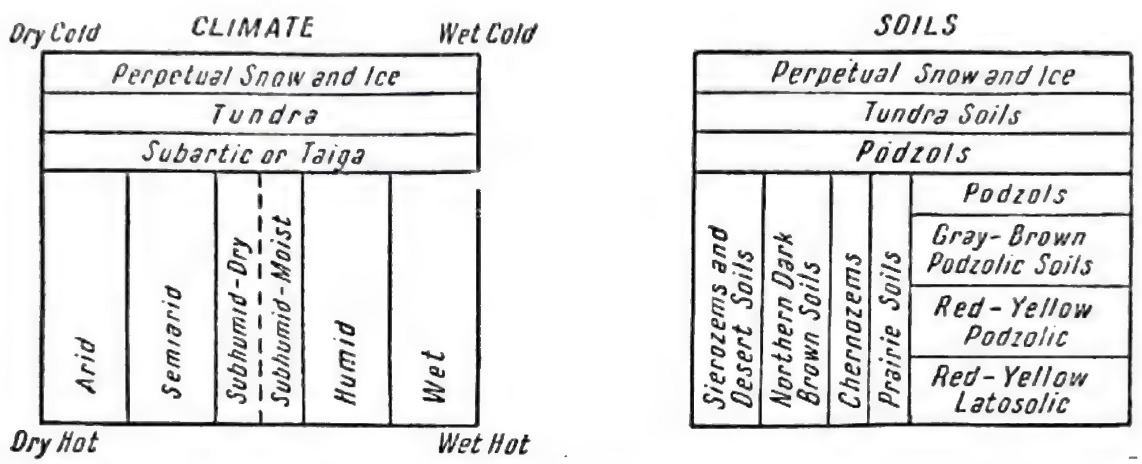

Fig. 2. Distribution of climatic types as related to distribution of major zonal soils.

tion. That is, crop production was determined for Class 1 land as defined by the Bureau of Reclamation (United States, Department of Interior, Bureau of Reclamation, 1953). The gross crop values were derived from farm budget studies supported by data from irrigated land, or where no large scale projects yet exist by data from experiment stations and development farms. Modal levels of managerial ability were assumed under current agricultural technology applied in the western states. Prices for crops were based on 250 price indexes (1910—1914=100). For each Great Soil Group studied, the mean gross crop value, the standard error of that mean, the number of observations involved, and the index of irrigation productivity are given in table 1. The index is simply computed as per cent of mean production on the Southern Desert Soils.

From data in table 1 a regression model (Ezekiel and Fox, 1959) may be constructed. In this model the Great Soil Group is the qualitative independent variable and gross crop value the quantitative dependent variable. The correlation coefficient for the model was found to be 0.80. Thus irrigated crop production on Class 1 lands shows a good correlation with the Great Soil Groups. Because of the variability residing in samples within Great Soil Groups the data were further tested by determining the variance ratio. The F value was found to be 4.325 and was significant at the 0.01 level. Thus the Great Soil Groups do indeed represent separate universes of irrigated crop productivity in the Western United States.

The model may be quantified by assigning numerical values of 1 through 6 to each of the Great Soil Groups from highest to lowest index of irrigation productivity. This shows that the relationship is exponential. For this model:

$$Y = 17 + 0.2\, e^{x},$$

Where: Y = index of irrigation productivity,
x = numerical designation of Great Soil Group.

The regression model is graphically depicted in figure 3 below. From the regression model it is seen that the Great Soil Groups explain about 64

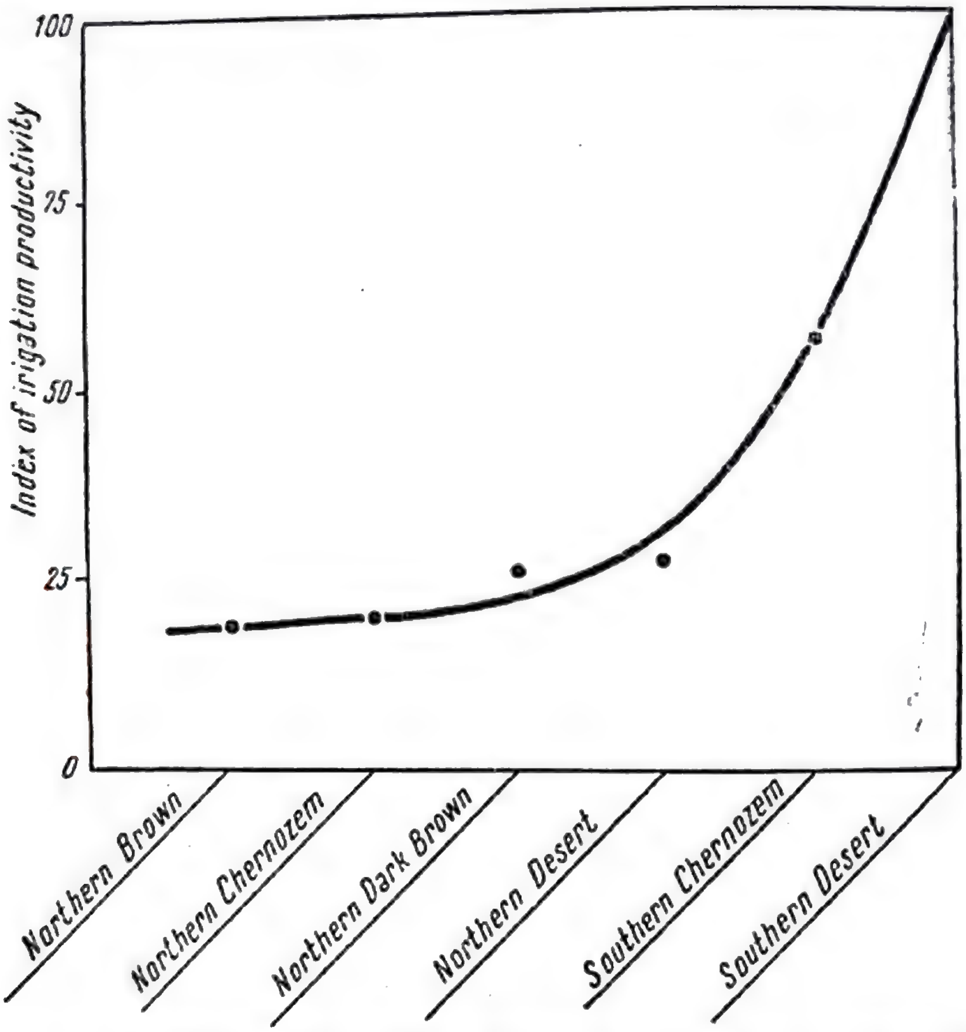

Fig. 3. Regression model showing relationship between the Great Soil Groups and the Index of Irrigation Productivity.

per cent of the variation occurring on Class 1 land under technological and managerial levels operating in the Western States. A portion of the unexplained variance may be ascribed to the influence of economic, social, and local climate influences. Large areas of azonal soils are also irrigated. These

soils tend to develop agricultural patterns characteristic of the adjoining zonal soils. This is best illustrated by the soils of the Pacific Valleys shown on figure 4. The mix of soils in this region almost universally produces high gross crop values. The highly favorable climate which permits the growth of over 200 different crops thus exerts a primary controlling influence. In general, there is a progressive increase in the standard error of the mean with increases in gross crop value. This reflects the increasingly wider choice of enterprises available as climatic environment becomes more favorable for the growth of a larger number of crops.

Examination of broad regional patterns further shows that within particular Great Soil Groups there are important localized influences of climate which permit specialty crops to be grown with resulting high gross crop values. This is well illustrated in study of frost hazard by Mason (1958). He develops an intricate pattern of frost-free, frost-rare, intermediate, frost-liable, and frost-subject land all occurring within an area of 10 square miles. Frost-subject land with restricted crop adaptation may occur within one-half mile of frost-free land with wide crop adaption. Similarly, care is exercised in the selection of and designation of irrigable lands in the Pacific Northwest apple producing regions. The frost-subject lands occur in intimate association with lands capable of producing apples which have a low frost hazard. Moreover local climatic influences on crops vary within short distances over much of the western landscape. The average climatic conditions on individual farms or small tracts differ from those of the local region mainly because of slope and exposure (Brooks, 1951). Fundamentally this difference is one involving the amount of solar energy received. Accordingly this factor is an important contributor to wide variations observed in the gross crop value within some members of the Great Soil Groups.

Economic and Social Factors

Economic and social factors exert a profound influence upon the pattern of irrigated agriculture. These are dynamic factors which continually alter the patterns of farm types. Bressler (1963) describes a complex model for specifying land use patterns. The model involves interrelations between agricultural and nonagricultural sectors of the economy, between land and other resources and between farm and nonfarm uses of land. A complex of interactions is visualized between available resources, technology, alternative uses, consumer demands and preference in a spatial context with appropriate interconnections in the form of transfer, processing and marketing costs. The model is dynamic to accomodate changes in technology and tastes, for interactions between and within major sectors, and for all the serial interconnections of these variables. With this complex of interactions, tending over time toward general equilibrium levels, the irrigation far-type patterns over the Great Soil Groups can thus be expected to respond sensitively to advances in technology and the progress of the general economy.

The principle of comparative advantage has been widely used to explain patterns of farm types. According to this principle, farmers in a com-

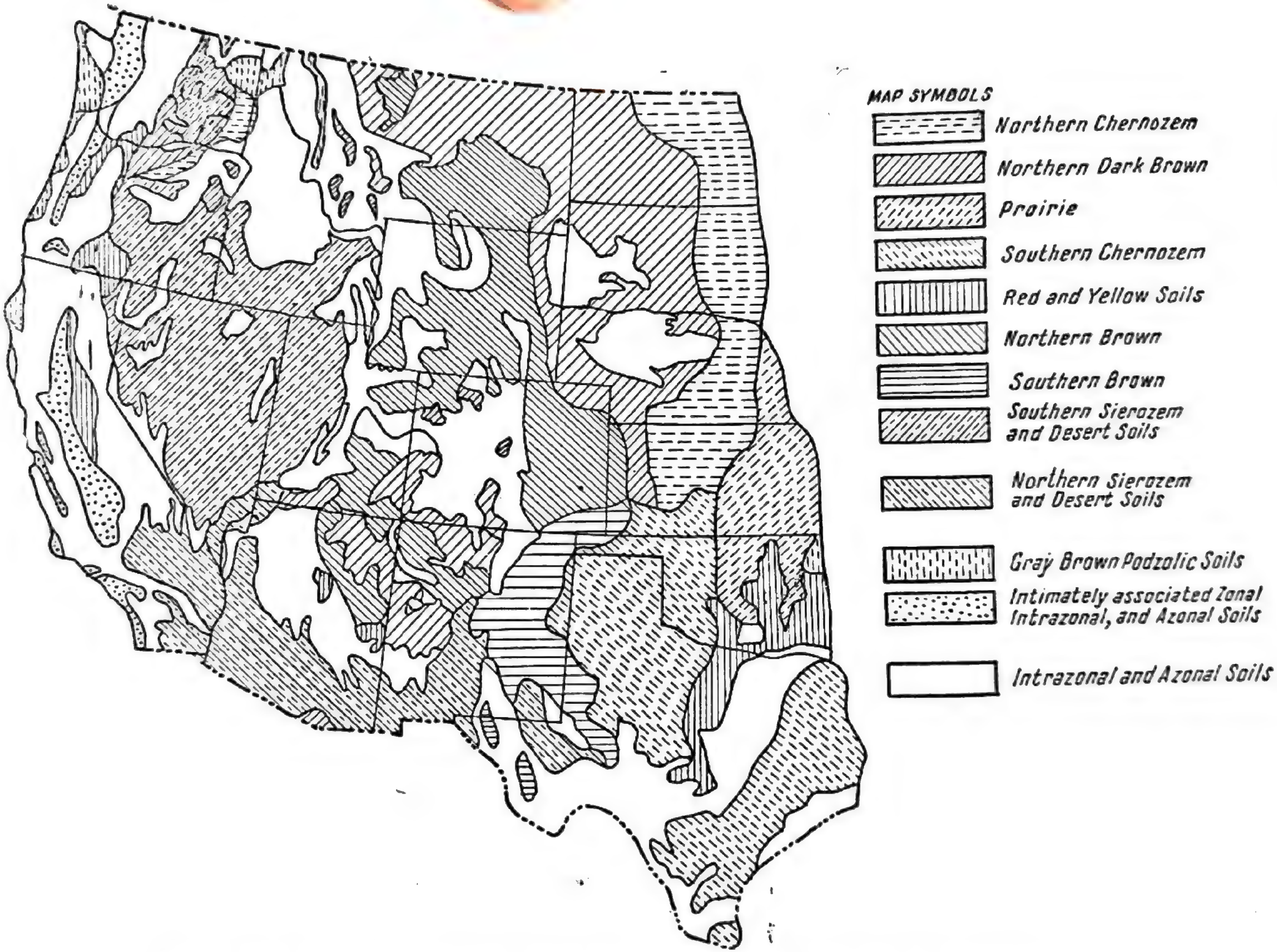

Fig. 4. Great Soil Groups of Western United States (United States, Department of Agriculture. 1).

petitive economy tend to produce products or combinations of products that yield maximum net farm incomes under a given set of circumstances. Again changing technology and movements in supply and demand will cause shifts in the comparative advantage and hence land use patterns. Within this broader context farmers may select enterprises according to the principles of: diminishing returns, substitution among products, and equimarginal returns. Therefore a broad spectrum of considerations faces the farmer in selecting an enterprise or combination of enterprises. These include: available land, labor, and capital; price structures; available machinery and agricultural chemicals; marketing potentials; ownership or occupancy of land; tax structures; land values; water cost and availability; and Government policies. In the final analysis these factors are conditioned in application by the personal preferences and skills of the farmer.

The patterns of irrigation farm types on the Great Soil Groups are influenced by social factors. The goals of people are closely tied to the investments they make. People are motivated to make the investment through their system of value judgments. An elegant analysis by Brewster (1959) indentifies three sets of value judgments. These he identifies as the work ethic, the democratic creed, and the enterprise creed. He shows that actions of people are fundamentally tied to these value judgments. Application of these judgments thus creates a portion of the variability observed in the irrigation farm-type patterns on the Great Soil Groups.

Klages (1942) distinguishes between natural and artificial social environments and their influence on crop distribution. He considers the natural environment to be one in which a production enterprise is developed and survives on its own merits without aid or interference of definitely superimposed economic stimulation or inhibition. On the other hand, artificial environment is created by the establishment of various forms of subsidies or inhibitions to production. With respect to crop patterns he relates that world-wide operation of the principle of comparative advantage is interfered with by creation of economic and social barriers such as import duties, tariffs, and import quotas. Thus producers may grow crops in areas where climatic and land factors are not most favorable for their production At the national level, government programs may similarly influence th crop patterns on irrigated land. This arises through the alteration of the price relationship among enterprises and applications of the acreage allotment systems.

GREAT SOILS GROUPS AND IRRIGATION FARM-TYPE PATTERNS

Within the context of the dynamic interaction principle, the broad regional association of the Great Soil Groups to evolving farm-type patterns may be presented. The patterns reflect stability arising from the impress of the climatic and land factors. The influence of the surrounding dryland agriculture on the irrigated land use patterns is evident. Maps showing generalized location and distribution of the Great Soil Groups and the irrigated

lands in the 17 Western States are shown in figures 4 and 5, respectively. In 1950 the irrigated land in farms over the 17 Western States totaled 30,738,000 acres, or less than 3 per cent of the 1.123 million acres of total land

Fig. 5. Generalized map showing location of major irrigation developments in Western United States.

in farms throughout the United States (United States Department of Agriculture and United States, Department of Commerce, U.S. Census of Agriculture, 1959). However, the value of crops harvested from these irrigated lands may range up to onethird of the value of all crops harvested. The irrigated subset of the Great Soil Groups produce forage for livestock and dairying field crops, and a large variety of vegetable and specialty crops. With respect to the latter, these soils produce 100 per cent of the commercial U.S. production of apricots, artichokes, honeydew melons, hops, lemons, olives dates, figs, garlic, nectarines, prunes, English walnuts, almonds, and fil-

berts. During late fall, winter, and early spring the warmer regions provide most of the U.S. supply of fresh spinach, peas, onions, lettuce, asparagus, broccoli, cantaloupes, carrots, cauliflower, and celery.

Shifts in the observed crop patterns derived from influence of the economic and social factors will occur. Bressler (1963), for example, contemplates that in the mountain states land use adjustments should involve expansion of range livestock, and of livestock and dairying on present and potential irrigated land and an increase in acres in cotton, fruits, vegetables, and dairying on irrigated land in the southern portion of these states. For the Pacific Coast states, he projects regional production adjustments to include expansion of fruits and vegetables with national requirements, some increases in livestock, and an increase in cotton acreage in California. Increases are also expected in the dairy industry and related hay-feed crops largely to meet fluid milk needs. New trends in agricultural economic research (Heady and Egbert, 1964; Egbert and Dumenil, 1959) aimed at defining efficient regional allocation of farm products and programed supply prices may provide bases useful in devising policies for adjustments in farming consistent with modern conditions and concepts of economic development. As such policies evolve there will be further shifts in the farm-type patterns on irrigated land.

Brown

The Brown Great Soil Group has brown surface soil grading at a depth of one or two feet into a highly calcareous horizon. The profile has developed in a temperate to cool, semi-arid climate under short grasses, bunch grasses, and shrubs. In the Western United States, they occur principally in a belt from central Montana, through central Wyoming, eastern Colorado, and eastern New Mexico. Smaller acreages are distributed in western Texas, western Kansas, northeastern Arizona, and in scattered areas of Utah and Idaho. Most of the irrigated Brown soils occur within an elevation range of 300—6,500 feet above sea level.

Farm types generally include livestock with a cash crop sideline wherever the growing season permits, or all livestock at the higher elevations. At the southern end of the Brown soils the typical farm type tends to shift to general farming with less dependence on livestock. Here alfalfa, corn and sorghum are the important crops. However, range livestock or beef fattening in association with diversified general farming is most typical of the largest area of the Brown Soils. Sugar beets, dry beans, potatoes, alfalfa, pasture, corn and small grains are typical crops. At elevations above 6,000 feet, alfalfa, pasture, and barley are the major crops. Fruit production is relatively unimportant on the largest portion of Brown soils because of the high elevations and associated dangers of killing frosts during the critical bloom period. However, there are a few valleys within this group that succesfully raise

apples and other hardy fruits. The average gross crop value on optimum land is about $79 per acre and ranges from $45 per acre in the colder areas of limited crop adaptation to $110 in the warmer more diversified areas.

Northern Chernozem

These soils have a black or grayish-brown surface, grading into light colored calcareous material at two to six feet. They have developed in a temperate to cool subhumid climate under tall and mixed grasses. In the Western United States these soils occur principally in the eastern portions of North Dakota, South Dakota, and Nebraska. Some are also found in northern Kansas and in the Palouse area of the Pacific Northwest. About 80 per cent of the total rainfall occurs during the growing season. Thus irrigation is supplemental to rainfall and varies in importance from year to year with the rainfall distribution. There are generally several dry periods during July and August. Timely applications of irrigation water during these periods are essential for high yields.

Over most of the North Dakota portion the growing season is too short to mature corn. Spring wheat is the important dryland crop in this state with lesser amounts of pasture, flax, oats, and barley. Current plans propose the eventual development of a one million-acre irrigation project in this area. It is anticipated that the present, essentially one- crop dryland economy, would change to an integrated dryland-irrigated economy with higher yields and a larger dependence on livestock.

The northern limit of climatic adaptation for corn is situated near the southern boundary of North Dakota. From here to the southern boundary of South Dakota, corn is the predominant dryland crop. A very large irrigation project is also being planned for this portion of the Chernozem soil group. Irrigation would furnish ample water at critical stages of corn growth for increasing its yield, and would permit diversifying with such crops as sugar beets, and alfalfa. Livestock would also be expected to contribute a higher proportion of farm income with irrigation than under dry farm conditions. At present irrigation development in North and South Dakota is sparse.

In the Northern Chernozem soil area of Nebraska and Kansas the frostfree period is about 180 days. Corn and sorghum are the principal crops with lesser acreages of sugat beets, beans, and alfalfa. Much of the feed and forage is fed to livestock on the farm or sold as cash crops to large feed-lot operators.

Throughout the Northern Chernozem area the farm types are closely associated with livestock production. In the northernmost portion, general farming with feeder livestock production will occur under irrigation. In the southern portion, which is close to excellent markets, beef fattening is important. Gross crop values on optimum land range from $ 42 to $ 142 with an average of about $ 85 per acre.

Northern Dark Brown

These soils are characterized by a dark brown surface soil grading into a whitish calcareous horizon at a depth of 1—1/2 to 3 feet, developed under mixed tall and short grasses in a temperate to cool semi-arid climate. As shown in figure 4, they are extensive in the northern and central Great Plains and occur in smaller areas in the Pacific Northwest and high plateaus of the Rocky Mountain Region.

In the northern Great Plains portion of this group irrigation has typically developed on the terrace systems of river valleys. The growing season ranges from 120 days in the north to 180 days in the Central Plains (United States, Department of Commerce, National Atlas of the United States, 1962). Severe winters and late spring frosts are unfavorable for fruit and the principal crops are alfalfa hay, feed grains, and cash crops such as grain, potatoes, sugar beets, and beans. The farm types are chiefly range livestock and the principal irrigated crops are alfalfa, silage, and feed grains which provide winter feed. Typical farm units include both irrigated lands and adjoining areas of dryland range and grain.

In the central Great Plains widely diversified general farms have developed which include extensive areas of sugar beets, potatoes, and beans as well as alfalfa hay, cash and feed grains. Some livestock are fattened and shipped for slaughter to nearby population centers but livestock feeding is not the major source of farm income. Farther east in areas of higher rainfall the farms include nonirrigated alfalfa, small grains, and sorghum together with irrigated corn, alfalfa, and small grains.

The principal farm types on the Northern Dark Brown soils in the Great Plains are livestock, general, and cash grain. The gross crop value on optimum land ranges from $ 60 per acre in livestock enterprises in the north to $ 95 on diversified farms in the southern part of the area.

Irrigation farming in the Rocky Mountain Plateau area has generally developed to provide winter feed for range livestock, with alfalfa, small grains, and corn silage as the principal crops. General cash crops, fruit, and specialty crops are grown where the growing season exceeds 150 days. The gross crop value on optimum land ranges from $ 45 to $ 150 per acre.

In the Pacific Northwest the Northern Dark Brown soils are developed with a growing season similar to those of the central Great Plains; however, the mild winters permit growth of fruits as well as general cash crops. Studies show gross crop values per acre on optimum land of $ 200 on farms devoted to crops such as alfalfa, sugar beets, and potatoes. Gross crop values of $ 275 per acre are obtained on farms that include specialty crops such as apples and asparagus as well as general crops. On specialty farms devoted to apples on the Northern Dark Brown and associated azonal soils, the gross crop values for optimum land are as high as $ 700 per acre.

Northern Sierozem and Desert

These are gray and grayish-brown soils of variable texture closely underlain by calcareous material. The profiles were developed in an arid climate under short grass and desert vegetation. They are principally distributed in southeastern Oregon, southern Idaho, Nevada, and western Utah. Small areas occur in parts of Washington, Wyoming, and Colorado. The largest contiguous irrigation developments occur on the Snake River Plain of Idaho and along the base of the Wasatch mountains in Utah.

Yield and quality of adapted crops are generally excellent because of the dry atmosphere and cool nights. Potatoes, dry beans, sugar beets, and alfalfa all yield exceptionally well. The potato plant is unusually well adapted to these soils. The excellent quality of the potatoes is reflected in premium prices obtained. The frost-free period of the irrigated lands in this soil group varies from about 80 to 180 days. Most of the concentrated potato production occurs in the area with less than 120 frost-free days. Alfalfa, pasture, sugar beets, dry beans, and peas are the most common crops grown in the group. In small areas with favorable local climate, fruits such as apples, cherries, prunes and peaches are grown.

General farming with some specialization is the predominant farm type on most of the irrigated lands. Dairying in association with general farming is an important farm type near the larger cities. In the sparsely settled areas where limited water supplies have restricted irrigation to small areas, the major irrigated farm type is beef cattle production in association with dryland range. Gross crop values on optimum land range from about $ 45 to $ 155 per acre and average about $ 99.

Southern Chernozems and Desert

These soils have dark brown to reddish brown surfaces underlain by brown or red horizons, grading below into light colored material that is calcareous at 3 to 6 feet. They were developed in a warm subhumid to semi-arid climate under a mixed tall- and short -grass prairie. They occur principally in western Texas and Oklahoma, and in smaller areas of eastern New Mexico and southern Kansas. The frost-free period over these soils varies from 180 to 240 days.

Cotton and sorghum are the principal crops where the growing season exceeds 200 frost-free days . In areas with less than 200 frost-free days sorghum and winter wheat are the important crops. In addition, barley, soybeans, vegetables and cow peas are grown. Livestock enterprises are generally not important throughout this area. Farm types consists of cotton, sorghum, or general farms. Gross crop values on optimum lands range from $ 158 to $ 328 per acre with an average of $ 225.

Southern Sierozem and Desert

These are gray, and reddish soils of variable texture developed on alluvial fans, and terraces in the hot southwest deserts under a native cover of desert shrubs and short grass. The subsoils are generally red or reddish brown and contain high concentrations of calcium carbonate. They occur under a rainfall of 3 to 12 inches, are only slightly leached, and are highly productive under irrigation. The growing season ranges from 200 to 330 days and is generally more than 240 days. From 60 to 175 days have maximum temperatures above 90°F and mean January daily minimum temperatures range from 20 to 40°F (United States, Department of Commerce, National Atlas of the United States, Weather Bureau, 1962). The climate and soils are thus suitable for a wide range of crops.

Irrigation development has been characterized by a wide diversity of crops. A large portion of the crop acreage consists of cereals and forage crops such as barley, sorghum, and alfalfa hay, which are grown both as cash crops and for livestock enterprises. Field crops such as cotton and sugar beets are extensively grown, and in local areas high intensity specialty crops are predominant. Those include vegetables such as lettuce, melons, carrots, tomatoes and sweet corn, and subtropical fruits such as grapefruit, oranges, and dates.

This soil group is characterized by high gross crop income due to high yields of all crops, and the high prices realized for specialty crops. This is intensified by the long growing season which permits double or triple cropping of some vegetables, and off-season marketing at premium prices.

The total gross crop value from 763,300 acres receiving water from Federal projects in 1960 was $ 249,600,000 or $ 327 per acre (United States, Department of Interior, Bureau of Reclamation, Crop Report and Related Data, 1960). Of this, $ 86,350,000 was received from vegetables; with a value of $ 680 per acre. The next ranking individual crop was cotton with $ 61,400,000 or $ 405 per acre. Fruits, chiefly subtropical, comprises $ 25,460,000 or $ 622 per acre. Thus fruits, vegetables, and cotton which comprised 41 per cent of the irrigated area, comprised nearly 70 per cent of the gross crop value. The range in gross crop value on optimum land, ranges from $ 215 to $ 815 per acre.

Intimately Associated Zonal Azonal and Intrazonal Soils

These soils, occuring in the Pacific valleys, are too intimately associated to separate on the schematic map in figure 4. They are developed under a wide range of climatic and geological conditions. They include members of the Sierozem, Non-calcic Brown, Red and. Yellow, and Prairie Great Soil Groups, associated with Alluvial, Rendzinas, Solonchak and Solonetz soils.

The region is characterized by mild winters, widely variable rainfall with dry summers, and by growing seasons of 160 to 200 days in the north, and 240 to 330 days in the south (United States, Department of Commerce, National Atlas of the United States, 1962). The long growing season and mild

winters are favorable for a wide diversity of crops. The dry summers, in the hot interior valleys are particularly favorable for the production of dried fruits and high quality hay and cotton. In coastal valleys, the cool humid summers are favorable for many tree fruits, truck crops, berries and other specialty crops. Throughout the area as a whole the largest portion of the irrigated lands are devoted to alfalfa hay, grain, and field crops, however, extensive areas of fruits, vegetables, and other specialty crops are grown, and in certain areas these crops are predominant.

The diversity of cropping patterns and crop values for areas of longer growing season may be typified by the Central Valley and Cachuma Projects of California (United States, Department of Interior, Bureau of Reclamation, Crop Report and Related Data, 1960). In 1960, of 729,400 acres irrigated in the Central Valley Project, 101,000 acres, or 14 per cent were devoted to grain crops consisting chiefly of barley, corn, and sorghum; 172,700 acre sor 24 per cent were devoted to forage crops consisting chiefly of alfalfa and irrigated pasture, and 241,400 acres, or 34 per cent consisted of miscellaneous field crops, chiefly cotton. Thus cereals, forage and field crops accounted for 71 per cent of the total irrigated cropped areas. The remaining 29 per cent consisted of fruits and nuts, vegetables, seed, and nursery; however, the gross crop value from these crops was $ 110,800,000 or 52 per cent of the total. Leading crops in terms of gross value were cotton, grapes, oranges, alfalfa, potatoes, and canteloupes which produced $ 143,758,000 or 67 per cent of the total.

In the Cachuma Project near Santa Barbara, California, fruit, chiefly lemons, comprised 83 per cent of the 1960 irrigated cropped area and 65 per cent of the total gross crop value. Vegetables and nursery, comprising only 9 per cent of the cropped area, contributed more than 32 per cent of the gross crop value. The wide range in crop values included $ 195 per acre for castor beans, $ 542 for lemons, $ 1,080 for fresh market beans, $ 1,968 for berries, and $ 8,300 per acre for nursery crops.

In the Willamette Valley, the growing season ranges from 160 to 200 days. Dairying and beef are important in the area and grass or grassclover pasture are the principal crops. However, specialty crops such as strawberries, raspberries, snap beans, sweet corn and many other vegetables are an important source of income. Because of the wide diversity of crops that may be grown throughout the Pacific valleys, the gross crop value on optimum land for significant farm types ranges from $ 160 to $ 1,000, and for individual enterprises, as high as $ 8,300 per acre.

MULTIPLE-PURPOSE WATER RESOURCE DEVELOPMENT

The needs for and methods of accomplishing water and land resource development programs are also broadly associated with the distribution of irrigated farm types and the related Great Soil Groups. Resource policy applied to particular regions strives to promote national objectives. Here the over-riding determinant in considering the best use of water and related land resources is the well being of people. The development should be formulated to achieve sustained production of crops, to meet economic benefit-

cost principles, assure repayment of reimbursable allocated costs, encourage further economic development both agricultural and industrial, and to provide for balanced growth of a region. Within this context development potentials should be assessed with respect to all purposes including: irrigation; hydroelectric power; domestic, municipal, and industrial water supply; water quality control; flood control and prevention; navigation; fish and wildlife development; outdoor recreation development and preservation; drainage; and watershed protection and management. In a given region, projects are formulated by selecting the purpose to be served, the physical means of development, the size of the facilities and service area, the method of operation for project works, and the management program for land and water areas included in the project. The marked differences in the physical and economic environment existing across the expanse of the Great Soil Groups thus require different types of projects to best meet the national and local goals of development.

These principles may be illustrated by several examples. In the Great Plains Region, which is characterized by the general farming and livestock farm types, economic stabilization and growth were highly important development objectives. The primary needs involved development of irrigation, flood control, navigation, and hydroelectric power. Other purposes were woven into the fabric of the comprehensive plan. Because moderate to low farm incomes were involved, the development of hydroelectric power assisted in financing the irrigation works. As a result irrigation of Northern Chernozems, Northern Dark Browns, and associated azonal and intrazonal soils were undertaken which would otherwise not have been possible.

The need for flood control in the Great Plains regions is great. Although semi-arid to subhumid climates prevail, torrential rainstorms are not uncommon. Due to the extensive areas drained by the water courses, reservoirs for flood control need to be large and therefore require the reservation of extensive areas for surcharge. Frequently the need to discharge the captured flood flows immediately after the flood to maintain available reservoir space precludes conservation of the waters for irrigation or hydroelectric purposes. Thus, major problems of competition among uses needed to be resolved to achieve a balanced development.

Resource development is fitted to stabilization of agricultural production in the livestock enterprise patterns, characteristic of the Northern Dark Brown, Sierozem, and related azonal and intrazonal soils of the intermountain valleys. Potential farm income under irrigation is comparatively modest; hence design and size of facilities are constrained by the repayment prospects.

The narrow intermountain valleys commonly provide efficient reservoir sites. Structural details of these dams are usually quite different from the massive, low dams of the plains country. High head power drops provide electric power at low cost. Flood control capacity is not needed in as great quantity and can also be provided at low cost. Sediment storage allowances need not be as great in the mountain areas because of the more stable physical properties of the surface materials.

The intermountain regions of the United States have not given rise to large population concentrations, and for this reason the demands for electric power and domestic water usually occur at the peripheries of the mountainous areas. This factor requires power and water transmission facilities differing significantly from those on the plains.

Transmountain diversion projects have been constructed in many places to divert water from areas of abundence to areas of scarcity. Project power output is utilized to assist in the delivery of water where needed. Pumped storage is utilized to maximize project power output at periods of peak demand. The availability of low-cost electric power has stimulated industrial development, particularly in the mineral and forest product categories. The accompanying population growth provides markets for the output of irrigated farms. The need grows for project water in manufacturing and domestic uses.

The arid environment of the speciality farming areas characterized by the Southern Chernozem, Sierozem, Desert, Brown and related alluvial soils provides challenges to development quite different from the plains and intermountain regions. The high proportion of land to available water requires the utmost in water conservation design and practice. High temperatures and low humidity justify extra care and expense in reducing wasteful vegetation, in selecting the most productive soils, and in recovery and reuse of water. Balanced use of ground and surface water supplies is mandatory. Plants for treatment of brackish and saline waters are included in our latest project plans.

The greatest challenges to produce refinements in irrigation engineeing and economy occur in the arid regions. Anything short of full-scope multiple purpose development fails to optimize the scarce water resource. Financial return from the use of water is greatest in these regions and justifies high-cost investments. Refined developments of the lands by the irrigators are made to maximize efficiency of water use and to reduce labor costs. System designs frequently involve extensive use of concrete-lined or pipe conveyance systems, often involving water transport over long distances.

INDUSTRIAL AND ECONOMIC DEVELOPMENT

The physical environment which gave the soils of the Western United States their principal characteristics also contributed to a diversity of commercial activity. The effect of irrigation development is significantly different over the wide range of physical and economic settings that occur in the Western United States. Again, the broad association of farm-type categories and the related Great Soil Groups provides a basis for broad categorizing the impact of irrigation development.

On the general farms in the Central Great Plains, the Northern Dark Brown Great Soil Group is predominant. Here industrial development is relatively sparse, due to the thinly populated agricultural areas and the generally low concentration of mineral resources. Reclamation development has enhanced the economic base in numerous ways. Irrigation of land formerly used for grazing or for extensive dryland farming increases crop production

manyfold. On a typical project the output of agricultural products was multiplied 13 times due to irrigation development. Such increased production and higher returns give rise to commercial activities on a scale much broader than is possible without irrigation. While industrial areas in the eastern section of the United States received a large share of the business volume created by the new demands for machinery and other manufactured goods, local industries also form to build specialized equipment and to construct project and farm facilities. Irrigated areas generally are capable of supporting a much larger local population than comparable adjacent dryfarmed areas.

The sugar beet is an important irrigated crop on the general farms of the plains region. The commerce generated by this crop is highly important to the local economic base. In a typical year, sugar beets produced on Federal Reclamation projects constitute a $47 million business and provides the equivalent of 2,900 man-years of employment at prevailling wages in the sugar manufacturing industry (United States, Department of Interior, Bureau of Reclamation, 1960).

The sharply differing physical environment found on the Sierozem and Desert soils of the intermountain area and on the Chernozem, Dark Brown, and Prairie Soils of the Great Plains leads to the conclusion that the economic and industrial complex of each will offer equally great contrast. The agricultural potential of the intermountain area is relatively lower without irrigation than that of the plains. But the economic potential of the intermountain valley lands is generally on a higher order when irrigated because of the opportunities for specialization in crop production and also because of the close integration of irrigated lands and adjacent grazing lands.

The commerce linked to the production of truck crops and stone fruits is of greater magnitude than that described for the production from irrigated farms of the plains. Local processing of these crops is a basic industry which contributes importantly to the strength and well-being of the local economy (United States, Department of Interior, Bureau of Reclamation, 1963).

Irrigation's greatest economic achievements, however, occur on the Desert, Sierozem and associated azonal soils of the Southwest, where climatic environment favors subtropical crops having gross values ranging up to $1,000 per acre. The associated trade and income generated in the economy of the area reach equally high levels.

The rise of modern towns and cities on the desert is only a part of the story of western Reclamation. From these desert lands come the bulk of the Nation's winter fruits and vegetables, and a large share of the Nation's more "exotic" crops, such as olives, figs, dates, avocados, hops and similar specialities. Worthless arid lands are transformed by water resource development into a vital part of the economic fabric of the Nation. Benefits are mutually enjoyed by the local and distant regions as a result of the trading of their specialized industrial and agricultural products.

While these benefits are attributable to irrigation development, other benefits accrue to the electric power generated at the dams, and to protection from flood damages provided on the river plains. Recreation opportu-

nities-boating, fishing, hunting, and swimming — on project reservoirs enhance area commerce and add to the well-being of the populace.

Thus, the remote and originally desolate waste areas are converted from dependency status to that of contributors to the overall economic strength of the Nation. Population, investment, and cultural facilities can be more widely distributed in this way. Some of the Nation's finest and fastest-growing cities have their origins in the irrigated desert regions of the western part of the country.

CONCLUSIONS

Patterns of irrigation farm types and associated enterprises express interactions of climate, land, economic, and social factors operating over time. Fundamental concepts of plant ecology and soil science suggest that factors of climate and land overshadow influences of economic and social factors. This was tested for irrigated conditions in the Western United States using gross crop value as a singlevalue index of land use and yield under adjusted prices and optimum soil conditions. For a selected set of Great Soil Groups: Northern Brown (NB), Northern Chernozem (NC), Northern Dark Brown (NDB), Northern Desert (ND), Southern Chernozem (SC), and Southern Desert (SD) gross crop value increased in the order NB<NC<NDB<ND<SC<SD. The regression model of the relationship showed that 64 per cent of the variability is explained by the Great Soil Groups (Table 1). Irrigated land use patterns are thus highly correlated with the Great Soil Groups.

Table 1

Relationship Between Gross Crop Value of Irrigated Class 1 Land and Various Great Soil Groups

Great Soil Group	No. of. obs.	Mean Gross Crop Value	Index of Irrigation Productivity
Northern Brown	17	79 ± 4	18
Northern Chernozem	12	85 ± 7	20
Northern Dark Brown	22	93 ± 11	21
Northern Desert	24	99 ± 9	23
Southern Chernozem	8	225 ± 19	52
Southern Desert	6	433 ± 88	100

Variability of gross crop value under irrigation in a given soil region generally increases as climate favors wider crop adaptation. While the physical environmental factors determine what will or will not grow, the economic and social factors profoundly influence what is grown. A complex of economic interactions are involved between agricultural and nonagricultural sectors of the economy, between land and other resources, and between farm and nonfarm uses. Value judgments of farmers operate across this spectrum of interactions thereby further influencing the irrigated land use patterns.

While climate, and to a lesser extent land, renders stability to the patterns, economic and social factors cause dynamic pattern shifts over time. Where rainfall over or near irrigation developments permits a dryland agriculture to develop, the patterns of farm types on irrigated land express an integration with the dryland agriculture.

A broad correlation thus exists between water resource development and the great soil groups.

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SUMMARY

Irrigated land use patterns show interactions of climate, land, economic and social factors operating over time; these can be correlated with the Great Soil Groups. Climate and soils overshadow economic and social factors. A regression model using gross crop value as an index of land use and yield under adjusted prices and optimum soil conditions showed that 64 per cent of the variability of gross crop value is explained by the Great Soil Groups. This variability generally increases as climate favors wider crop adaptation. While climate and land give stability to irrigated land use patterns, economic and social factors cause dynamic shifts over time. Differences in physical and economic environment across the expanse of Great Soil Groups require different types of projects for maximum contributions to the goals of multipurpose water resource development.

RÉSUMÉ

Les plans d'aménagement des terres irriguées présentent des interactions du climat, de la terre, des facteurs économiques et sociaux agissant à longueur de temps; ceux-ci peuvent être mis en corrélation avec les Grands Groupes de Sol. Le climat et les sols éclipsent les facteurs économiques et sociaux. Un modèle de régression utilisant la valeur brute de la récolte en tant qu'indice d'utilisation des terres et du rendement à des prix réglés et dans des conditions optima de sol a montré que 64% de la variabilité de la valeur brute de la récolte est expliquée par les Grands Groupes de Sol. Cette variabilité augmente généralement à mesure que le climat favorise une adaptation plus large des cultures. Tandis que le climat et la terre confèrent la stabilité aux plans d'utilisation des terres irriguées, les facteurs économiques et sociaux y causent, à la longue, des changements dynamiques. Les différences dans le milieu environnant physique et économique à travers l'étendue des Grands Groupes de Sol exigent des projets de types différents, afin de contribuer au maximum au but poursuivi, du développement aux fins multiples des ressources en eau.

ZUSAMMENFASSUNG

Die Nutzungspläne von bewässertem Boden lassen Wechselwirkungen zwischen Klima, Land, wirtschaftlichen und sozialen Faktoren sehen, die sich im Laufe der Zeit auswirken; sie können mit den Hauptbodentypen in Korrelation gebracht werden. Klima und Böden überschatten die ökonomischen und sozialen Faktoren. Ein Regressionsmodel, das den Bruttowert der Kulturen als einen Index für Bodennutzung und Ertrag bei angemessenen Preisen und optimalen Bodenbedingungen zugrundelegt, zeigte, dass 64 v.H. der Veränderlichkeit der Bruttokulturenwerte durch die Hauptbodentypen erklärt wird. Diese Veränderlichkeit nimmt im allgemeinen zu, sofern das Klima eine ausgedehntere Kulturenanpassung begünstigt. Während Klima und Land Nutzungsplänen von bewässertem Boden Beständigkeit verleihen, bewirken die wirtschaftlichen und sozialen Faktoren auf die Dauer dynamische Veränderungen. Unterschiede in den physikalischen und ökonomischen Umweltfaktoren mitten durch die Fläche der Hauptbodentypen erfordern verschiedene Projekt-Typen, um einen bestmöglichen Beitrag zu den verfolgten Zielen der vielen Zwecken dienlichen Entwicklung der Wasserhilfsquellen zu leisten.

DISCUSSION

W. FÖLSCHER (South Africa). What data were used in correlation equation which showed the response of Great Soil Groups in U.S.A. to irrigation development?

F. E. DOMINY. The correlation was actually between water supply and crop response and not really soils as such.

D. KIRKHAM (U.S.A.). From the tremendously increased yields, and high income per acre from land reclaimed by the U.S. Bureau of Reclamation, does the U.S. Government receive back the costs (as from increased taxes paid by benefitted farmers) of reclamation projects?

F. E. DOMINY. In a national setting of intense competition for the use of public funds, the Reclamation program in the United States is unique because it is virtually self-sustaining. Through repayment contracts or direct charges on a unit basis, the recipients of project services repay to the United States more than 90 per cent of all Government funds invested. But even more significant, the vastly increased economic activity in local areas and regions which results when these modern multipurpose projects reach maturity, itself generates much new wealth for the Nation. Measured in increased Federal tax revenues alone this wealth returns to the National Terasury an amount many times the size of the original investment by the Government.

WATER-LOGGED AND PEAT-BOGGY SOILS, THEIR GENESIS, PROPERTIES AND MELIORATION METHODS

I. S. LUPINOVICH [1]

Water-logged and peat-boggy soils are widely developed in the non-chernozem zone, where rainfall exceeds evaporation.

Contrary to the podzolic and sod-podzolic soils of the plateaus, water-logged soils develop under a temporary or permanent excessive moistening due to waters of different genesis and composition: atmospheric, ground-water, deluvial and alluvial. A stagnant water regime predominates.

Depending upon soil forming conditions, three subtypes are distinguished: podzolic-boggy, sod-podzolic-boggy and sod-boggy soils.

Podzolic-boggy soils are developed under conditions of a periodic excessive moistening by atmospheric waters with a percolative water regime in the upper part of the soil profile and a stagnant regime in the lower part.

Soil reaction of soil solutions is very acid: pH (is KCl) is 3.2—4.0; base saturation is 15—20 per cent. Soils are very poor in P_2O_5 and K_2O; humus content ranges from 1 to 3 per cent; the Ch/Cf ratio [2] is less than 1.

Sod-podzolic-boggy soils have a percolative water regime with moistening by atmospheric waters. However, the lower part of the profile is affected by ground waters. These are richer in carbonates and other substances than atmospheric waters. The topsoil is acid: pH (KCl) is 4—4.6; base saturation is 35—50 per cent; the P_2O_5 content does not exceed 5 mgr per 100 gr of soil; the K_2O content is approximately the same; humus content is about 3.5 per cent (in some cases up to 10 per cent). Fulvic acids are predominant and the mobile aluminium content is high.

Sod-boggy soils develop mostly under grass vegetation, as a result of moistening due to frequently mineralised ground-waters. They have a slightly acid or neutral soil reaction; pH (KCl) is 5.3—7.5; base saturation is 65—95 per cent. They are rich in humus. Humic acids predominate. The Ch/Cf ratio exceeds 1. P_2O_5 content in the alluvial horizon reaches 40 and more mg per 100 g soil.

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[1] Academy of Sciences of the Byelo-russian S.S.R., U.S.S.R.

[2] Ch — humic acids; Cf — fulvic acids.

Peat-boggy soils are permanently waterlogged and have a stangnant water regime. Synthesis of the organic matter predominates over its decomposition. In the process of soil formation (simultaneously with soil formation) the organic deposit — peat — is formed.

Depending upon the character of moistening and the water composition three types of peat-boggy soils are distinguished. They differ in physico-chemical and biological properties and potential fertility:

1) Peat-boggy soils of a high-moor type formed as a result of land bogging by atmospheric waters;

2) Peat-boggy soils of a low-moor type, formed by the filling up of water reservoirs, as well as by the waterlogging of depressions with ground and run-off waters;

3) Alluvial-peat-boggy soils of the flood plains moistened by ground and alluvial waters.

Peat-boggy soils with an atmospheric moistening are characteristic of the northern part of the non-chernozem zone. Organic matter content is up to 95—98 per cent mostly of Sphagnum peat.

Such soils have a very low volume weight (0.04—0.08 g/cm^3) and an enormous moisture capacity, reaching 1700 and more per cent (air dry basis); pH (water) comes to 2.6. They are very poor in CaO, P_2O_5, K_2O and highly unsaturated base saturation — 10—15 per cent.

Peat-boggy soils of low-moor type have a more varied composition of the peat. This is mostly sedge-rush or sedge-grass peat with mixture of alder, birch and various species of willow, as well as Hypnum; its colour is dark or blackish-brown. It is more intensely decomposed than the similar soils of the high-moor type. The ash content varies from 8 to 20 per cent and more. The volume weight is 3—4 times higher than in the soils of the high-moor type and the moisture capacity is 2—3 times lower (about 600 per cent). The reaction of the medium is slightly acid or neutral. CaO content comes to 5 and more per cent and base saturation is 80—90 per cent. It is rich in nitrogen, its total content reaching 3.5—4 per cent and more.

Alluvial-peat-boggy soils have a higher ash content than the low-moor soils. This is associated not only with a greater degree of peat decomposition, but also with the accumulation of silt.

Under natural conditions the majority of waterlogged and peat-boggy soils, especially soils of the high-moor type, are not productive. They are very acid and poor in nutrients.

As for the nitrogen content and the biochemical properties, low-moor peat-boggy and alluvial soils are most suitable for development and cultivation of valuable agricultural crops.

During the first period of reclamation, a higher effective fertility of the peat-boggy soils is achieved by an intensification of the organic matter decomposition and an increase in this way of the available forms of nutrients, mostly of nitrogen.

An integral part in the melioration and first period of reclamation is the application of phosphorous-potassium and minor fertilizers (Cu, Co, Mo,

Mn, etc.). Fertilizers are applied depending upon the biological peculiarities of the cultivated crops.

In the southern and south-eastern part of the non-chernozem zone, in the forest-steppe and steppe zones, where the annual rainfall comes close to evaporation or is even less, the meliorative system should provide irrigation of crops during the dry periods. In areas where peat soils are part of sod-podzolic sandy and sandy-loam soil sequences, drainage weters may be used for irrigation of arable lands. Agricultural crops on light textured soil often suffer from moisture deficiency even in the non-chernozem zone.

Special attention should be paid to the application of tube drainage in the regulation of the water regime for waterlogged soils.

SUMMARY

Depending on soil formation conditions, three types of waterlogged soils are presented: podzolic-boggy, sod-podzolic-boggy and sod-boggy.

Three types of peat-boggy soils are also distinguished: peat-boggy soils of the high moor, type, peat-boggy soils of the low-moor type and alluvial peat-boggy soils.

In their natural state, most of the waterlogged and peat-boggy soils are not productive.

During the first stage of reclamation, a more intensive decomposition of the organic mass is needed so as to increase the availability of nutrient elements. An integral part of reclamation of the peat-boggy soils is the application of PK and trace elements (Cu, Mo), and eventually liming.

RÉSUMÉ

En fonction des conditions de formation du sol, trois types de sols à exces d'humidité sont indiqués: tourbeux podzolisé, dernopodzolique tourbeux et derno-tourbeux.

On distingue trois types de sol de marais-tourbeux: sols de marais tourbeux du type tourbière haute sols de marais tourbeux du type de tourbière basse et sols de marais tourbeux des plaines alluviales.

À l'état naturel, la plupart des sols engorgés et de marais tourbeux ne sont pas productifs.

Pendant le premier stade de la mise en valeur, une décomposition plus intense de la masse organique est nécessaire, afin de faire augmenter l'accessibilité des éléments nutritifs (N primaire). L'application de PK et d'oligo-éléments (Cu, Mo) et éventuellement du chaulage chez les sols du type de tourbière haute, constitue une partie intégrale de la mise en valeur des sols de marais tourbeux.

ZUSAMMENFASSUNG

In Abhängigkeit von den Bodenbildungsverhältnissen werden drei Typen von versumpften Böden: podsolig-moorig, derno-podsolig-moorig und derno-moorig, dargestellt.

Es werden drei Typen von Torfmoorböden unterschieden: Torfmoorböden vom Hochmoortypus, Torfmoorböden vom Niederungsmoortypus und alluviale Torfmoorböden.

Im natürlichen Zustand sind die meisten versumpften Böden und die Torfmoorböden nicht produktiv.

Während der ersten Urbarmachungsstufe ist eine stärkere Zersetzung der organischen Masse notwendig, um die Aufnehmbarkeit der Nährstoffelemente (primär-N) zu steigern. Die Anwendung von PK und Spurenelementen (Cu, Mo) und gegebenenfalls die Kalkung bei Böden vom Hochmoortypus bilden einen wesentlichen Bestandteil der Urbarmachung der Torfmoorböden.

DISCUSSION

W. H. VAN DER MOLEN (Netherlands). Are there any informations in USSR about the lowering of the soil surface after the drainage of peat soils? This lowering may be considerable in many cases.

I. S. LUPINOVICH. There is ample information in the USSR on the lowering of the level (surface) of peat-boggy and boggy soils after reclamation and agricultural utilization.

The lowering of soil surface following reclamation is connected with the following factors:

a) the depth of drainage;

b) the botanical composition, the pH (or acidity) and the degree of decomposition of the organic matter i.e. of the peat; c) the types of crops cultivated and the nature of agricultural technique.

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BODENPROZESSE IN MELIORATIONSBÖDEN DER FLUSSTÄLER IN TAIGA UND WALDSTEPPE DES EUROPÄISCHEN TEILS DER UdSSR

I. N. SKRINNIKOWA, S. T. WOSNJUK, W. L. KOTSCHETKOWA[1]

Das charakteristische Hauptmerkmal des Moorbodenbildungsprozesses ist die Akkumulation des halbzersetzten organischen Stoffes — des Torfes — bei der überschüssigen Bodenanfeuchtung mit atmosphärischem und Grundwasser, die arm an Sauerstoff sind. Als Quelle des organischen Stoffes dient die spezifische hydrophile Moorvegetation. Während der Bildung neuer Schichten des Moorbodens werden seine unteren Schichten biologisch wenig aktiv, sie werden an Mikroorganismen verarmt, die Torfbildung verzögert sich allmählich, es findet eine Torfkonservation statt. Der Boden verliert seine effektive Fruchtbarkeit und verwandelt sich in ein torf-organisches Gestein (Gerassimov, 1937; Skrinnikowa, 1961). Die Melioration und nachfolgende landwirtschaftliche Kultivierung verändern die Richtung des Prozesses der Bodenbildung; die Zersetzung des früher akkumulierten Torfes wird sein Hauptmerkmal.

In Moorböden setzt die überschüssige Anfeuchtung die Wirkung der Zonalfaktoren zu einem gewissen Grade herab. Nach der Melioration ist der Einfluss solcher Faktoren, wie die Temperatur, das Verhältnis zwischen Niederschlägen und Verdunstung, Einwirkung der Gesteine, die dem Torflager unterliegen und chemische Zusammensetzung des Grundwassers sehr verstärkt. Die Trockenlegung und nachfolgende Verbesserung der Moorböden führen unter verschiedenen natürlichen Bedingungen zur Bildung neuer Bodentypen, die keine Analoga unter den anderen jungfräulichen und kultivierten Böden aufweisen (Skrinnikowa, 1961).

In diesem Bericht ist dies am Beispiel der Meliorationsböden im Tale des Flusses Inta (Nordtaiga der Komi ASSR[2]), der intensiv kultivierten Moorböden im Flusstal Jachroma (südlicher Teil der Taiga[3]), Territorium der Moskauer Moor-Versuchsstation) und der Meliorationsböden im Tale des Flusses Trubezh und seiner Nebenflüsse (Panfilow Versuchsfeld, Wald-

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[2] Untersuchungen wurden von W. L. Kotschetkowa durchgeführt.

[3] Untersuchungen wurden von I. N. Skrinnikowa durchgeführt.

Steppe der Ukrainischen SSR[1]) veranschaulicht. Alte Aueterrassen dieser Flusstäler sind reich an Torf. Torfmassive werden mit modernen Flussbetten durchschnitten, die sie dränieren.

Dank der Deluvium- und Alluviumverschlammung und der Grundwasserwirkung besitzen diese Böden einen höheren Aschengehalt, manchmal sind sie reich an Vivianit und geben reiche Ernten der Gemüse- und Futterkulturen bei einer zweckmässigen Benützung. In den letzten zehn Jahren wurden von uns die Bodenprozesse in Meliorations- und Torfböden untersucht. Die Hauptresultate dieser Untersuchungen werden hier angegeben.

Klimatische Bedingungen. Die Flusstäler (Inta, Jachroma und Trubezh) weisen ganz verschiedene klimatische Bedingungen auf (Tabelle 1 und 2).

Tabelle 1

Mitteltemperaturen der Luft (vieljährige)

Gebiet	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Jahr
Inta	—17,3	—18,2	—14,9	—2,9	2,2	10,1	14,1	12,2	5,8	—2,2	—11,0	16,2	3,2
Jachroma	— 9,7	—10,1	— 5,5	4,5	11,1	16,2	17,2	15,6	10,9	4,2	— 2,8	—7,0	3,7
Panfilow-Versuchsfeld	— 7,6	— 5,6	— 1,5	7,7	14,2	18,5	20,3	19,4	14,0	6,4	1,3	—3,5	6,96

Tabelle 2

Mittelsumme der Niederschläge in mm (vieljährige)

Gebiet	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Jahr
Inta	19	11	16	24	44	60	60	72	70	49	32	19	476
Jachroma	15	13	17	29	56	71	84	78	57	44	25	17	504
Panfilow-Versuchsfeld	16	17	15	35	41	44	64	50	34	35	32	30	413

Die Temperatursumme der Vegetationsperiode (> 10°C) ist 1 120°C für Inta, 1 944°C für Jachroma und 2 702°C für die Panfilow-Versuchsstation.

Nach den mehrjährigen Angaben beträgt der Anfeuchtungskoeffizient der benachbarten Grundstücke 1,04 für Ust-Zilma (330 km östlich vom Inta Fluss); 1,20—1,24 für die Moskauer Versuchsstation; 0,88 für Kiew (80 km westlich vom Panfilow-Versuchsfeld).

Obwohl der Unterschied in der jährlichen Summe der Niederschläge und im Charakter ihrer Verteilung auf die Jahreszeiten nicht gross ist, spielen die Niederschlags- und Grundwasser in der Bildung der Torfböden dieser Täler eine verschiedene Rolle. Niedrige Temperaturen im Sommer und das flache Relief im Flusstal der Inta führen dazu, dass die sogenannten "wei-

[1] Untersuchung wurden von S. T. Wosnjuk durchgeführt.

chen" Niederschlagswasser eine grosse Rolle in der Bildung der Torfböden spielen. Viel beträchtlicher ist die Bedeutung der Grundwasser in der Bildung der Torfböden im Jachroma-Tal und besonders der Torfböden im Trubezh-Tal und seinen Nebenflüssen, wo die Grundwasser stark mineralisiert sind und die Verdunstung im Sommer sehr gross ist. Die Mehrheit der Torfböden im Inta-Tal haben eine Sphagnumtorfdecke. Von der Tiefe 20—50 cm für Hochmooruntertypen und der Tiefe 5—10 cm für Übergangsuntertypen lösen sich Moostorfe mit Riedgrastorf, das Holzüberreste einschliesst ab. Die Böden haben einen sehr niedrigen Aschengehalt: von der Tiefe 20—30 cm bis zu 100 cm beträgt er 2,3—3,0% ; nur in den oberen Horizonten erreicht er 5—8%, seltener 16% infolge der Staubablagerung und deluvialer Verschlammung.

Die Zunahme des Aschengehalts in den oberen Horizonten führt nicht zu ihrer Anreicherung mit mobilen Elementen, da der unlösliche Aschenrest hauptsächlich aus Quarz und schwer verwitterndem Feldspat besteht. Die Böden besitzen eine sauere Reaktion (pH in oberen Horizonten schwankt von 3,8 bis 4,6 und pH des KCl-Auszuges von 2,9 bis 3,8). Diese Böden sind sehr nährstoffarm.

Die Untersuchungen des Wasser- und Wärmehaushalts, der Auftautiefe der jungfräulichen und intensiv kultivierten Böden und einiger biochemischer Prozesse, die in den Jahren 1958—1961 durchgeführt wurden, haben gezeigt, dass durch Entwässerung und den nachfolgenden Anbau halb zersetzte obere Torfhorizonte im Sommer der Vertrocknung unterworfen sind; ihre Feuchtigkeit fällt bis auf 39—45%. Die grosse Zunahme der Menge der mit Luft gefüllten Poren verwandelt den Oberflächen-Bodenhorizont in eine Wärmeisolierschicht, die den Wärmehaushalt der unteren Bodenhorizonte verschlechtert. Wenn in jungfräulichen Böden Frosthorizonte im Sommer fehlen oder sich in der Tiefe von 1 m befinden, so erscheinen diese Frosthorizonte in bearbeiteten Böden in einer Tiefe von 40—60 cm (Fig. 1a). Tiefer als 60 cm tauen diese Böden selbst in einem heissen Sommer nicht auf. Das über der eingefrorenen Schicht sicht befindliche Hangwasser fehlt in bearbeiteten Torfböden. Also, durch Melioration und Anbau verwandeln sich die Hoch- und Untermoorböden im nördlichen Teil der Komi ASSR in sekundäre Frostböden (Abb. 1).

Die Stallmist- und Mineraldüngergabe führt zur grösseren Vielfältigkeit der Artenzusammensetzung der Mikroorganismen in den oberen Horizonten, aber die Menge der Mikroorganismen fällt mit der Tiefe in den bearbeiteten Böden schneller ab als in den jungfräulichen Böden, was mit der Verschlechterung des Wärmehaushalts verbunden ist.

Die Melioration und Bodenbearbeitung tragen deswegen nicht zur stärkeren Torfzersetzung und zum Übergang der Stickstoffverbindungen in die den Pflanzen zugänglichen Formen bei. Die Bearbeitung der Torfböden der nördlichen Taigagebiete muss darum nicht nur mit Düngerzufuhr, sondern auch mit Wärmemeliorationen (Aufhalten des Schnees, frische Düngerzufuhr, Waldstreifen den Feldern entlang und manchmal Sandmischkultur) begleitet werden. Einen ganz anderen Charakter der Bodenbildung beobachtet man während der Melioration und der Kultivierung der Torf-

böden in Flusstälern der Südtaiga. I. N. Skrinnikowa hatte in den Jahren 1953—1958 Bondenprozesse in gut kultivierten aschenreichen (eisenhaltigen und eisenkarbonathaltigen) Böden im Jachroma-Tal untersucht [1].

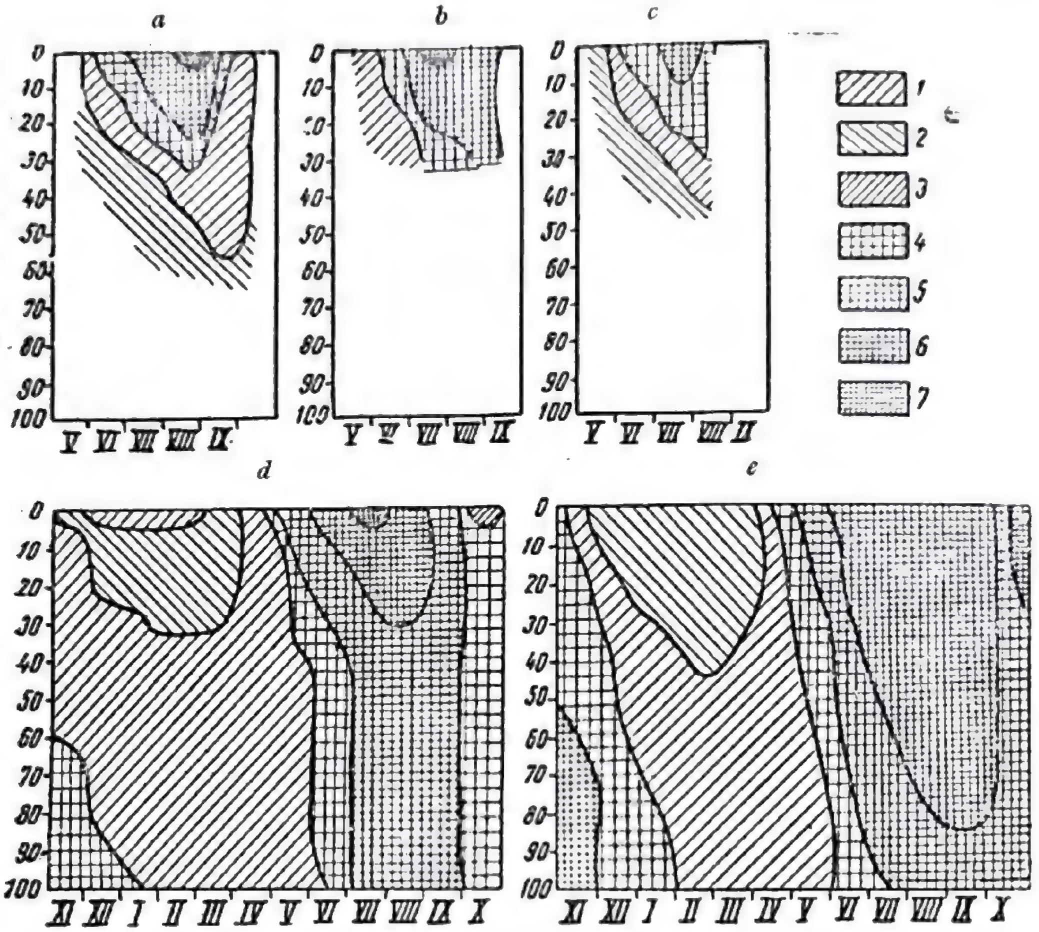

Abb. 1. Chronoisothermen der Meliorationstorfböden des Europäischen Teils der UdSSR: *a* — kultivierter niedrieger Torfboden im Inta-Tal, 1958; *b* — jungfräulicher niedrieger Torfboden im Inta-Tal, 1958; *c* — kultivierter niedrieger Torfboden im Inta-Tal, 1960; *d* — intensiv kultivierter humus-torf- und eisenhaltiger Kulturboden im Jachroma-Ta (vieljährige Angaben); *e* — kultivierter humus-torf- und eisen-karbonathaltiger Boden im Supoy-Tal; *1* — Unter —5°C; *2* — von —5°C bis 0°C; *3* — von 0°C bis +3°C; *4* — von +5°C bis +10°C; *5* — von +10°C bis + 15°C; *6* — von + 15°C bis +20°C; *7* — oben + 20°C.

Die Hauptbesonderheit der gut kultivierten Torfböden auf Riedgrastorfen besteht in einer gut ausgeprägten Zweigliedrigkeit des Bodenprofiles: die Ackerkrume, die aus gut zersetztem Torf besteht, besitzt eine gute Struktur und einen hohen Aschengehalt; der Torf des unterliegenden Horizonts

[1] Die Böden werden durch Verbindung von Drainierung und Schleusengräben getrocknet. Die Verbesserung dieser Böden wurde durch die Zufuhr der Kaliumdünger und Anwendung der Gemüse-Futterfruchtfolge durchgeführt. Die Böden wurden ab 1933—1934 kultiviert. Der Ertrag von Kohl war 70—90 t/ha, von Futterfrüchten 60—80 t/ha, von Heu vieljähriger Gräser 60—100 dz/ha.

hat einen niedrigen Zersetzungsgrad und schliesst die Reste der torfbildenden Vegetation ein. Sein Aschengehalt, spezifisches und Volumengewicht sind geringer. Dieser Horizont ist dauernd mit kapillarem Wasser gesättigt, weil die Ackerkrume ein günstiges Wasser- und Luftverhältnis für die Kulturvegetation besitzt.

Im Prozess der Kulturbodenbildung in den Ackerhorizonten der Meliorations- und Torfböden in Flusstälern der Südtaiga findet die Akkumulation von Ca, P, K, Cl, statt (Tabelle 3). Diese Akkumulation ist teilweise mit der K-P-und Cl-Düngerzufuhr in die Böden verbunden, die eine hohe Adsorptionsfähigkeit besitzen, aber hauptsächlich war die Ausfällung vieler Elemente an der Grenze zwischen der Ackerkrume und dem unterliegen den Horizont mit der Veränderung der Redoxbedingungen verbunden. Im unteren Horizont herrschen anaerobe Bedingungen vor, die Ackerkrume ist dagegen gut durchlüftet. Die obgenannten Ursachen tragen zur intensiven Entwicklung der biologischen Prozesse in der Ackerkrume bei. Der obere Teil

Tabelle 3

Aschengehalt, Aschenzusammensetzung und pH der Meliorations- und Kulturtorfböden in Flusstälern des Europäischen Teils der UdSSR (in % des trockenen Auszuges)

Böden	Tiefe in cm	pH-Werte:		Aschen	SiO_2	Fe_2O_3	Al_2O_3	P_2O_5	CaO	MgO	K_2O
		H_2O	KCl								
Sphagnumstorfboden des niedrigen Typs Inta-Tal	0—10	4,1	3,2	7,9		Nicht bestimmt*					
	10—24	4,5	3,5	4,3		"		"			
	30—40	4,5	3,5	2,4		"		"			
	50—60	4,7	3,6	3,0		"		"			
Derselbe, kultiviert im Jare 1954	0—10	4,7	4,1	16,3		"		"			
	10—20	4,5	3,8	16,8		"		"			
	50—60	4,5	3,7	2,8		"		"			
Humus-Torf eisenhaltiger Kulturboden Jachroma	0—10	6,63	w.b.	26,1	12,08	8,76	3,21	1,15	2,87	0,72	0,99
	10—20	6,47	"	20,4	8,34	7,31	2,53	0,82	2,62	0,39	1,03
	30—40	6,31	"	10,4	2,27	4,23	0,76	0,24	2,00	0,33	0,93
	60—70	6,37	"	13,9	3,03	3,97	1,53	0,20	3,42	0,37	w.b.
Humus-Torf eisenkarbonathaltiger Kulturboden Jachroma	0—10	6,98	"	33,09	14,00	8,70	2,01	1,05	10,07	0,42	0,38
	10—20	7,33	"	33,26	14,48	9,32	1,97	1,03	9,62	0,42	0,95
	30—40	7,25	"	7,20	0,92	1,28	0,68	0,24	3,99	0,26	1,13
	60—70	7,25	"	13,96	0,64	1,16	0,54	0,18	11,26	0,18	0,19
Eisenkarbonathaltiger Kulturtorfboden, Salz-Boden Panfilow-Versuchsfeld	0—10	7,2	"	34,5	2,83	7,90	2,61	0,24	16,85	2,95	0,22
	10—20	7,4	"	26,9	2,58	3,25	2,05	0,22	9,84	6,75	0,09
	40—60	7,5	"			Nicht bestimmt					
	80—100	7,3	"			"		"			

* Es wurde nur ein in HCl aufgelöster Teil der Aschen bestimmt.

dieses Horizontes enthält 85—90% der Kulturpflanzenwurzeln (nach Makarow).

Die Untersuchung des Temperatur- und Wasserhaushaltes der Kulturtorfböden liess die Ursachen solch eines grossen Unterschiedes zwischen der Ackerkrume und den unterliegenden Horizonten enthüllen. Vieljährige Angaben zeugen davon, dass nur die Ackerkrume der Torfböden dem Winterdurchfrieren unterworfen ist. Im Sommer erhöht sich die Temperatur der Ackerkrume dieser Böden bis 15 und sogar 20°C. Im unterliegenden Horizont beträgt die jährliche Temperaturamplitude 10—12°C. Im Winter sinkt die Temperatur nicht niedriger als —2° und im Sommer steigt sie bis auf 12—14C°. Die mechanische Zerstörung der torfbildenden Vegetationsreste bei der Bodenbearbeitung, sowie das Winterdurchfrieren und die biochemischen Prozesse im Sommer tragen zur Veränderung der organischen Substanz der Ackerkrume bei, und zwar zur Zertrümmerung und Zersetzung der torfbildenden Vegetationreste und zur Torfhumifikation.

Eine der wichtigsten Besonderheiten des Wasserhaushaltes in Kulturtorfböden ist die Störung der Kapillarverbindung zwischen der Ackerkrume und den unterliegenden Horizonten, die durch die Bearbeitung und den Strukturunterschied in diesen Horizonten hervorgerufen wird. Diese Kapillarverbindung ist schwach wiederhergestellt. Ausserdem tritt während des Durchfrierens der Ackerkrume manchmal ein physikalischer Riss zwischen der Ackerkrume und dem unterliegenden Horizont durch Bildung von Eiszwischenschichten ein. Die zweite Besonderheit des Wasserhaushalts dieser Böden ist die Entwicklung des „Hangwassers" in der Ackerkrume und im oberen Teil des unterliegenden Horizonts. Dank der hohen Wasserabsorptionsfähigkeit des Torfes und einer intensiven Evapotranspiration im Sommer besitzen die Kulturtorfböden im Jachroma-Tal einen periodisch perkolativen Wasserhaushalt (die Durchfeuchtung geschieht aber nicht jedes Jahr). Die obengenannten Ursachen: Regulierung der Zersetzung der organischen Stoffe mit Hilfe der Bodenbearbeitung, Düngung und Fruchtfolgen, eine hohe Absorptionsfähigkeit des Bodens, die Eigenart der Redoxbedingungen und des Wasserhaushalts tragen zur Verbesserung nicht nur der effektiven, sondern auch der potentiellen Bodenfruchtbarkeit bei. Eine andauernde Kaliumdüngerzufuhr als Chlorkalium führte jedoch dazu, dass dank der hohen Absorptionsfähigkeit dieser Böden Chlor vermutlich als Komplexverbindungen mit organischem Stoff und Eisen in diesen Böden akkumuliert wurde. Um eine ungünstige Chlorwirkung zu vermeiden, kann man die Menge der Kaliumdünger herabsetzen und ihre chlorfreien Formen anwenden[1]. Ausserdem empfehlen wir für die Verbesserung der Wasserversorgung solcher hydrophyler Kulturen, wie Kohl und für die Verminderung der Chlorkonzentration in der Bodenlösung, Sommerbewässerungen durch Beregnung durchzuführen. Bei der Bebauung der eisenkarbonathaltigen und salzhaltigen Torf-

[1] Während der Kultivierung steigt der Kaliumgehalt im Boden 3—4 mal (von 0,17—0,36 bis 0,65—1,82% auf dem trockenen Boden).

böden in der Waldsteppe der Ukraine (Versuchsfeld Panfilow, Supoy-Flusstal) steigt der Zersetzungsgrad des Torfes in der Ackerkrume. Der Gehalt an Kalzium steigt noch stärker an als im Jachroma-Tal. Eisen wird akkumuliert; die pH-Werte sind höher als 7, manchmal erreichen sie 7,9—8,0. Die Dauer der Vegetationsperiode und ein günstiger Temperaturhaushalt führen während der landwirtschaftlichen Ausnutzung dieser Böden zur Akkumulation stabiler organischer Stoffe. Im Sommer während der Entwässerung der oberen Schichten erreicht die Konzentration des wasserlöslichen Natriums im Wasserauszug 8—10 mäquiv. pro 100 g Boden. In den Böden des Panfilow-Versuchsfeldes wie auch in Torfböden des Jachroma wird die Störung der Kapillarverbindung zwischen der Ackerkrume und den unterliegenden Horizonten beobachtet. Darum spielen die Boden-und Grundwasser bei der normalen Entwässerung auf diesen Böden eine sehr geringe Rolle in der Wasserversorgung der landwirtschaftlichen Pflanzen. Die Beregnung ist eine wichtige Massnahme für die Verbesserung der Befeuchtung der Ackerkrume so wie für Herabsetzung der toxischen Konzentration der Bodenlösungen während der Dürreperiode.

Für die Erhöhung der Fruchtbarkeit der Kulturtorfböden im Jachroma-Tal und der Dneper-Nebenflüsse ist es notwendig, den Wasserhaushalt zu regulieren, Kalium- und manchmal Phosphordünger zuzuführen und Gemüse-Futter-Fruchtfolgen mit dem Wechsel der Hackkulturen und mehrjährigen Gräser anzuwenden. Die Fruchtfolge trägt zur Regulierung der Zersetzung des organischen Stoffes in den Torfböden bei.

Es können folgende Schlüsse gezogen werden:

1. Bei der Melioration und dem nachfolgenden Ackerbau der Torfböden verändert sich der Prozess der Bodenbildung beträchtlich: die Akkumulation des halbzersetzten organischen Stoffes—des Torfes—wird durch den Prozess seiner Zersetzung ersetzt.

2. Die Beseitigung des überschüssigen Wassers in den Torfböden trägt zur Verstärkung der Einwirkung der Zonalfaktoren bei. Darum werden unter verschiedenen natürlichen Bedingungen verschiedene Torfbodentypen gebildet, die sich sowohl von den natürlichen als auch von den Kulturmineralböden unterscheiden.

3. Die Melioration und der Ackerbau der Hoch- und Niedermoortorfböden in Flusstälern der nördlichen Taiga führen zur beträchtlichen Verschlechterung des Wärmehaushalts und zur Bildung der sekundärgefrorenen Torfböden. Neben der organischen und mineralischen Düngerzufuhr bedürfen diese Böden auch der Wärmemelioration.

4. Die Melioration und die Kultivierung der aschenreichen Torfböden in der Südtaiga erhöhen nicht nur ihre effektive sondern auch ihre potentielle Fruchtbarkeit.

5. Bei der Melioration und dem Ackerbau der aschenreichen Torfböden in den Flusstälern der Waldsteppe (Dnepr-Gebiet) verstärkt sich ihre Versalzung.

6. Die richtige Entwässerung und Anwendung von Düngern und Fruchtfolgen ist eine wichtige Bedingung der Verbesserung der Torfbodenfruchtbarkeit in der Südtaiga und Waldsteppe. In der Südtaiga ist es notwendig, bei den hydrophilen Kulturen Beregnung anzuwenden. In der Waldsteppe hat diese Massnahme eine besonders grosse Bedeutung.

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[ZUSAMMENFASSUNG

In diesem Bericht werden die Ergebnisse vieljähriger Untersuchungen über die Bodenprozesse in den meliorierten bebauten Torfböden der Täler in der Nord- (Inta-Fluss) und Südtaiga (Jachroma-Fluss), sowie in der Waldsteppe (Trubezh-Fluss) vorgelegt. Es wird gezeigt, dass die Melioration und die Erschliessung der Torfböden der Nordtaiga zu einer Verschlechterung ihres Temperaturhaushaltes und zur Bildung sekundärgefrorener bebauter Torfböden führt. Die fruchtbaren bebauten Torfböden bilden sich bei entsprechender Melioration, Nutzung, Fruchtfolge und Düngemittelanwendung in den Tälern der Südtaiga. In der Waldsteppe führt die Melioration der Torfböden in den Flusstälern zu einer Steigerung der Versalzung und Alkalisierung.

Es werden ferner Hinweise für eine Erhöhung der Fruchtbarkeit der meliorierten und bebauten Torfböden gegeben.

SUMMARY

In this report results of many years investigations on soil processes in meliorated river valley peaty soils of the northern (river Inta) and southern taïga (river Jachroma) and of the forest-steppe of Ukraina (River Trubezh) are presented. It is shown that melioration and development of peaty soils of the northern taïga lead to a deterioration of their temperature regime and to the formation of secondary frozen cultivated peaty soils. The fertile cultivated peaty soils are formed under correct reclamation, management, crop rotations and applications of fertilizers in the valleys of the southern taïga. In the forest-steppe melioration of peaty soils in the river valleys leads to an increase in salinization and alkalization.

Recommendations for an increase of fertility of meliorated and cultivated peaty soils are given.

RÉSUMÉ

Dans cette communication on présente les résultats des recherches à long terme sur les processus pédologiques se déroulant dans des sols tourbeux améliorés et cultivés des vallées de la taïga septentrionale (rivière Inta) et méridionale (rivière Jachroma), ainsi que la steppe à forêts (rivière Trubej). Il est montré que l'amélioration et la mise en valeur des sols tourbeux de la taïga septentrionale conduisent à une altération de leur régime de température et à la formation de sols tourbeux cultivés, gelés secondairement. Les sols tourbeux fertiles cultivés furent formés par les justes amélioration et utilisation, assolement et application d'engrais, dans les vallées de la taïga méridionale.

Dans la steppe à forêts, l'amélioration des sols tourbeux des vallées des rivières entraine un accroissement de la salinisation et de l'alcalisation.

On donne des indications pour augmenter la fertilité des sols tourbeux améliorés et cultivés.

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I+VI. 11

MELIORATIONSRAYONSEINTEILUNG, WASSERHAUSHALT UND PHYSIKALISCHE EIGENSCHAFTEN DER NASSBÖDEN IN DER SÜDLICHEN TAIGA

F. R. ZAIDELMAN, A. K. OGLENEW, W. G. WINOGRADOW [1]

In der vorliegenden Arbeit werden einige Resultate der Nassbödenuntersuchung in der südlichen Taiga für Meliorationszwecke erörtert.

Die Bildung der anaeroben Verhältnisse — und infolgedessen die Bodenvernässung — erfolgt als Ergebnis der Stauung des oberflächlichen Wassers oder des Grundwasseraustrittes, der Evolution der Pflanzendecke, der Wasserstauung über den als Ergebnis der Bodenbildung entstandenen wasserundurchlässigen Bodenschichten oder erfolgt als Ergebnis der Einwirkung des Menschen.

Die Bodenvernässung hängt mit dem hydrogeologischen Aufbau des Territoriums, mit seiner Geologie und seinem Klima zusammen. Verständlich ist daher eine gewisse geographische Gesetzmässigkeit (Provinzialität) in der Verbreitung der Nassböden und der Entstehung bedingter Ursachen. Wenn man unter einer Meliorationsprovinz ein grosses Territorium mit nahen bodengeologischen Verhältnissen und gleichen Vernässungsursachen zonaler Böden versteht, so können im landwirtschaftlichen Gebiet der UdSSR sechs Meliorationsprovinzen (Zaidelman, 1963) a) eingeteillt werden (Abb. 1). In Meliorationsprovinzen kommen aber azonale und intrazonale Böden vor, deren Vernässung unter anderen Bedingungen erfolgt. Für Projektierungsziele sollen Meliorationsprovinzen in kleinere Rayons eingeteilt werden. Der Meliorationsrayon ist ein Territorium mit Böden, die gleiche Vernässungsursachen haben (Zaidelman, 1961). Dieses Prinzip der Meliorationseinteilung bestimmt in der Regel auch die Gemeinsamkeit der Bodenentwässerungsart des Rayons.

Die Böden eines Meliorationsrayons werden nach dem Vernässungsgrad in Gruppen eingeteilt. Der Vernässungsgrad bestimmt die Zweckmässigkeit der Bodenentwässerung entsprechend ihrer verschiedenen landwirtschaftlichen Nutzung. Zur Zeit stellt man den Vernässungsgrad auf Grund visueller, in hohem Masse subjektiver Untersuchung des Profilbildes fest.

Die Bodendifferenzierung nach dem Vernässungsgrad soll an Hand der sorgfältigen Untersuchung des Wasserhaushaltes der Nassböden im mehrjährigen Zyklus auf der Grundlage der Nutzung zu verschiedenen

[1] Rosgiprowodschoz. Moskau UdSSR.

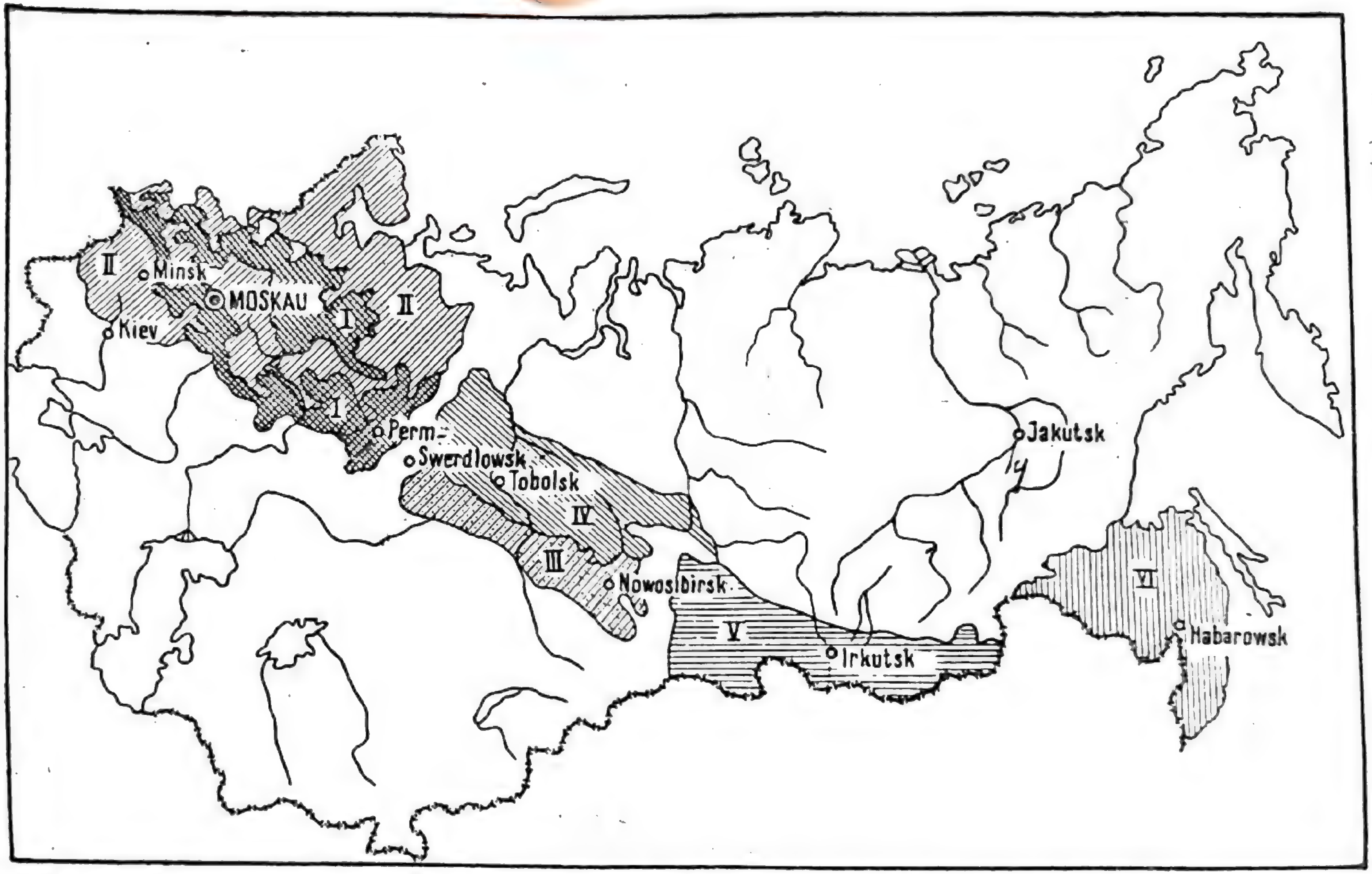


Abb. 1. Meliorationsprovinzen der Nassböden in landwirtschaftlichen Gebieten der UdSSR(schematische Karte): *I.* Provinz der durch Oberflächenwasser vernässten Podsole, Rasenpodsole und Moorböden des Europäischen Territoriums der UdSSR. *II.* Provinz der durch Süssgrundwasser vernässten Podsole, Rasenpodsole und Moorböden des Europäischen Territoriums der UdSSR. *III.* Provinz der vorwiegend durch Oberflächenmineralwasser vernässten jahreszeitlich-gefrorenen anmoorigen Salzböden, Wiesensalzböden und Moorböden im Süden Westsibiriens. *IV.* Provinz der durch Süssgrundwasser vernässten jahreszeitlichgefrorenen Rasenpodsole und Moorböden Westsibiriens. *V.* Provinz der vorwiegend durch Mineralgrundwasser vernässten, dauernd jahreszeitlich-gefrorenen und Wiesensabzböden, anmoorigen Salzböden und Moorböden Ostsibiriens. *VI.* Provinz der durch Oberflächensüsswasser vernässten Wiesenbraunerden und Moorböden des Fernen Ostens.

landwirtschaftlichen Zwecken durchgeführt werden. Diese Untersuchungen sollen im zonalen Aspekt betrieben werden, da bei verschiedenen Klimaverhältnissen die Böden mit gleichen Vergleyungsmerkmalen den verschiedenen Kulturpflanzen nicht gleiche Bedingungen für ihre Entwicklung bieten.

Von uns sind die Wasserhaushaltsuntersuchungen der staunassen Rasenpodsole (Zaidelman und Winogradow, 1964) und Aueböden (Zaidelman) mit feiner mechanischer Zusammensetzung in der südlichen Taiga durchgeführt worden. Für solche Böden ist die richtige Lösung der Frage über die Zweckmässigkeit ihrer Entwässerung im Zusammenhang mit ihrer grossen Verbreitung und dem erheblichen Kostenpreis der Dränage von besonders grosser Bedeutung. In unvernässten Rasenpodsolen und Rasenpodsolen mit zeitweiliger Staunässe im Unterboden hat das Feuchtigkeitsregime nicht nur mit mittlerer, sondern auch mit höherer Jahresniederschlagsmenge einen gleichartigen Charakter (Abb. 2). In schwach pseudovergleyten Rasenpodsolen tritt aber sogar in Jahren mit mittlerer Niederschlagsmenge in 120—130 cm Tiefe zeitweilige Staunässe auf, und relativ geringe Niederschläge verursachen ihre schnelle Erhöhung und die Bildung von Gravitationswasseransammlungen in der Ackerkrume. Für stark pseudovergleyte Böden sind hohe Staunässelage im Bodenprofil während der Vegetationsperiode und nachhaltige Gravitationswasseransammlung in der Ackerkrume charakteristisch.

Eine charakteristische Besonderheit der vernässten Rasenpodsole mit feiner mechanischer Zusammensetzung ist die zweischichtige Staunässelage. Bei der Entwässerung bedingt das die Notwendigkeit der Absenkung des Staunässestandes in tiefen Bodenhorizonte und die Beschleunigung des Gravitationswasserflusses aus oberen Horizonten durch verschiedene agrotechnische Massnahmen (Eriksson, 1957; Podlipenko, 1962). Eine Besonderheit des Wasserhaushaltes der Aueböden im Bereich der Nichtschwarzerdezone ist ihre periodische oder jährliche Überschwemmung. Aueböden sind nach Überschwemmung bis zur vollen Wasserkapazität gesättigt, und ihre Feuchtigkeit in der Vegetationsperiode hängt mit dem Wasserregime vor der Überschwemmung nicht zusammen. Eine Ausnahme sind die Böden, die nicht überschwemmt werden und Merkmale der zonalen Bodenbildung tragen.

Die Wasserhaushaltsuntersuchung zeigte, dass in unvernässten, tiefpseudovergleyten und, in einzelnen Jahren, mässig pseudovergleyten Böden die auf Grund einer Rechnung bestimmte Dauer der Überschwemmungsperiode mit der wirklichen Wasserstandslage im Flussbett zusammenfiel Stärker vernässte Böden werden immer für einen längeren Zeitabschnitt überschwemmt, als es aus den Angaben über den Wasserstand im Flussbett zu schliessen ist.

Zum Unterschied zu Rasenpodsolen wird in vernässten Aueböden, dank ihrer günstigen Struktureigenschaften und ihrer hohen Wasserdurchlässigkeit, keine Bildung zweischichtiger Staunässe beobachtet (Abb. 3).

Eine allgemeine Meliorations- und Agronomiebeurteilung des Wasserhaushaltes vernässter Rasenpodsole und Aueböden ist in Tabelle 1 dargestellt.

Die Untersuchungen des Wasserhaushalts und der hydro-physikalischen Eigenschaften vernässter Böden ermöglichen die Voraussage von Besonderheiten in der Arbeit der Dränage. In unvernässten, kurzfristig vernässten, mässig und stark pseudovergleyten Rasenpodsolen mit feiner mecha-

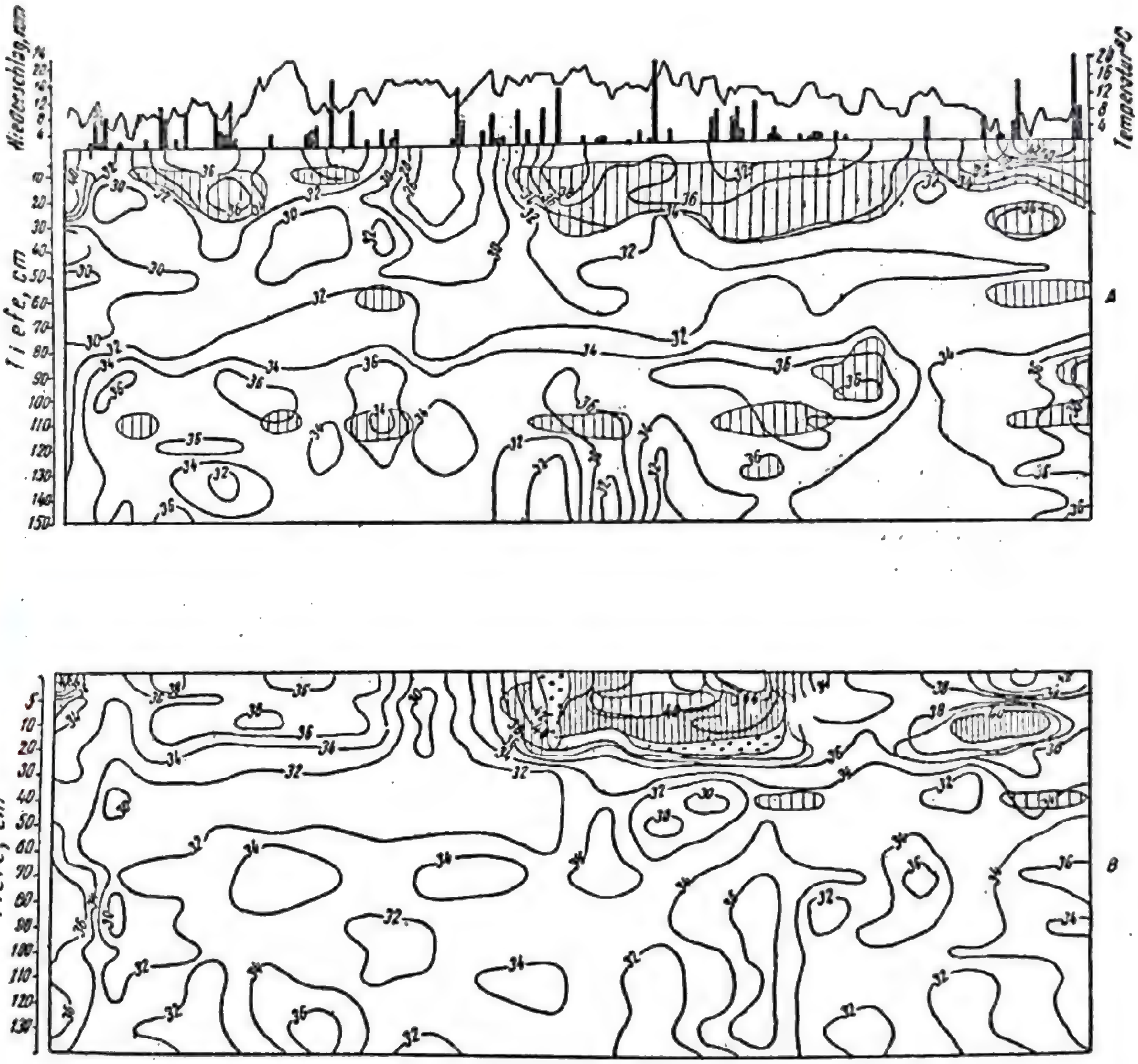
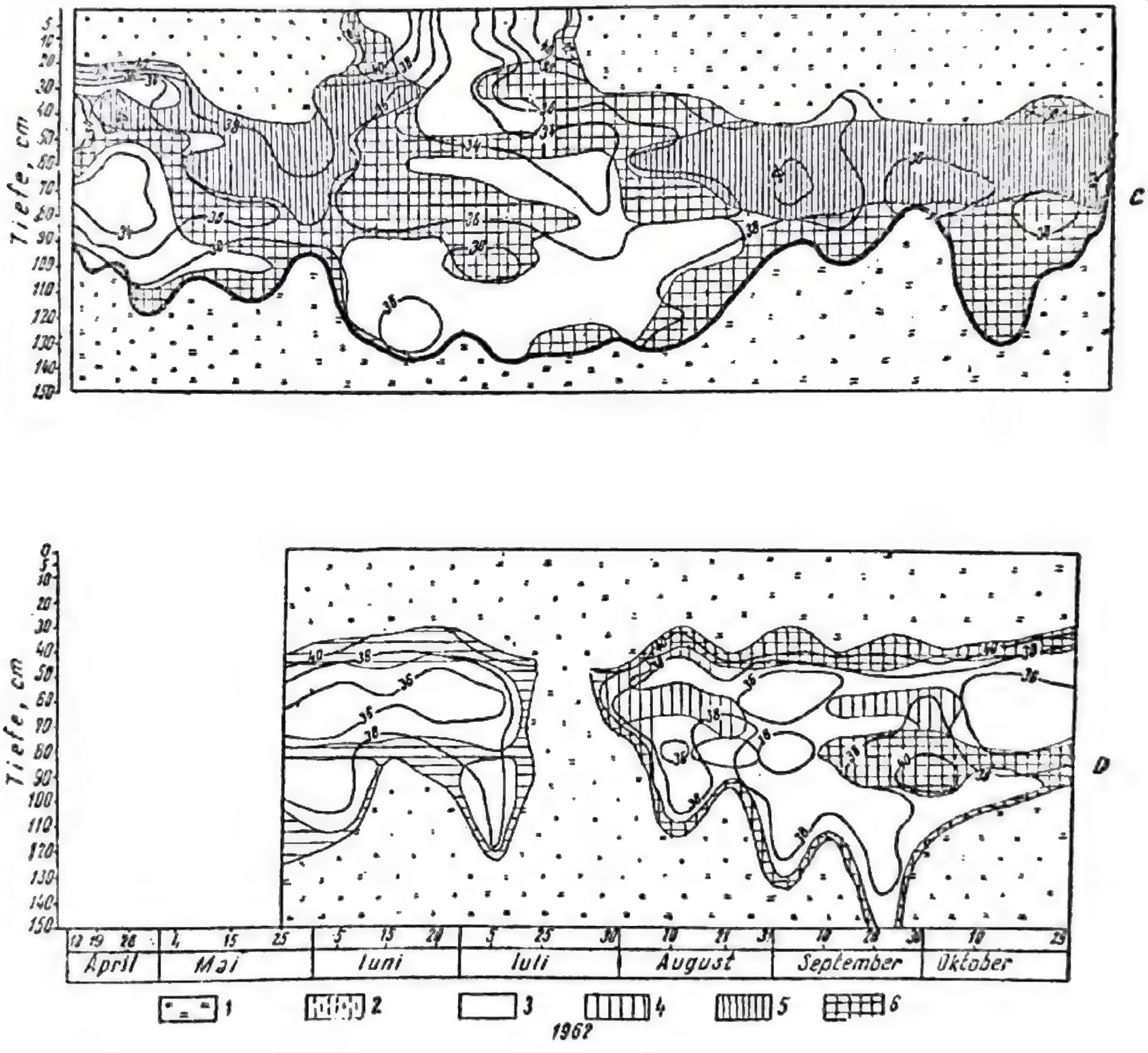
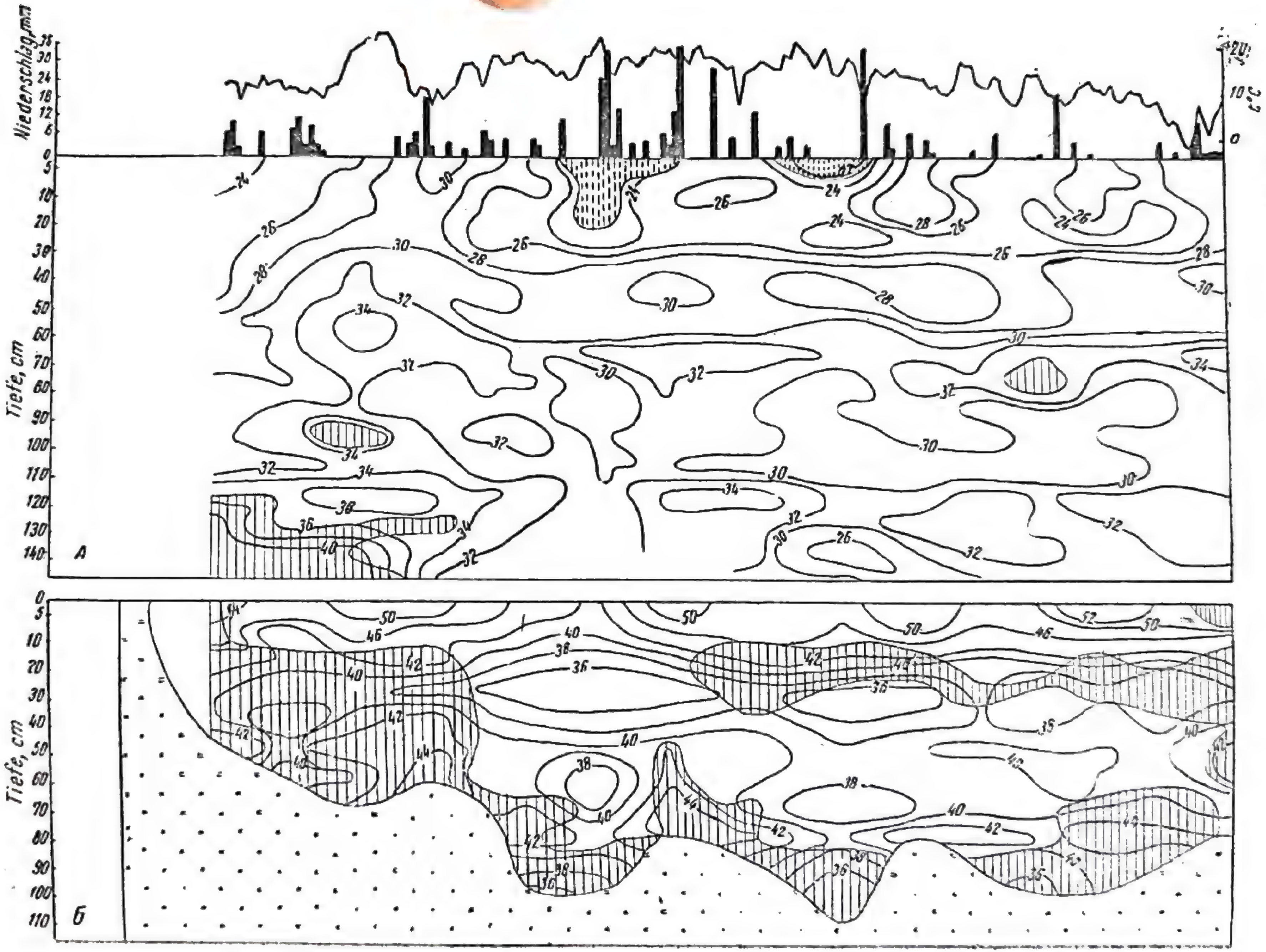


Abb. 2. Feuchtigkeitschronoisopleten der unvernässten und vernässten Rasenpodsole im feuchten Jahren 1962 (Die Feuchtigkeit in Prozent und Kategorien). Böden: *A* — lehmige Rasenpodsole; *B* — tief pseudovergleyte lehmige Rasenpodsole; *C* — mässig pseudovergleyte schwerlehmige Rasenpodsole; *D* — schwerlehmige Rasenpseudogleyböden.

nischer Zusammensetzung betrug die Feldkapazität im Untersuchungsfall in der Schicht 0—30 cm, bzw. 73,5; 77,0; 82,0 und 95,0% vom Gesamtporenvolumen. Die Arbeit der Landmaschinen ist bei einer Bodenfeuchtigkeit unter 70—75% vom Gesamtporenvolumen möglich. Daraus ergibt sich, dass die Feldkapazität selbst unvernässter Rasenpodsole dem kritischen Wert nahekommt. Demgegenüber ist die Feldkapazität unvernässter Aueböden nicht grösser als 50—55% vom Porenvolumen. Sie nimmt aber



Feuchtigkeitskategorien:
1. — volle Kapazität, Staunässe; *2* — von der Feuchtigkeit beim Welkepunkt bis zu der, der Unterbrechung des zusammenhängenden kapillaren Wassernetzes entsprechenden Feuchtigkeit (UKF); *3* — von UKF bis zur Feldkapazität; *4* — von der Feldkapazität bis 90% zu voller Wasserkapazität; *5* — von 90% zu voller Wasserkapazität bis zur vollen Wasserkapazität; *6* — von der Feldkapazität bis zur vollen Wasserkapazität.


Niederschlag, mm
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Tiefe, cm
A
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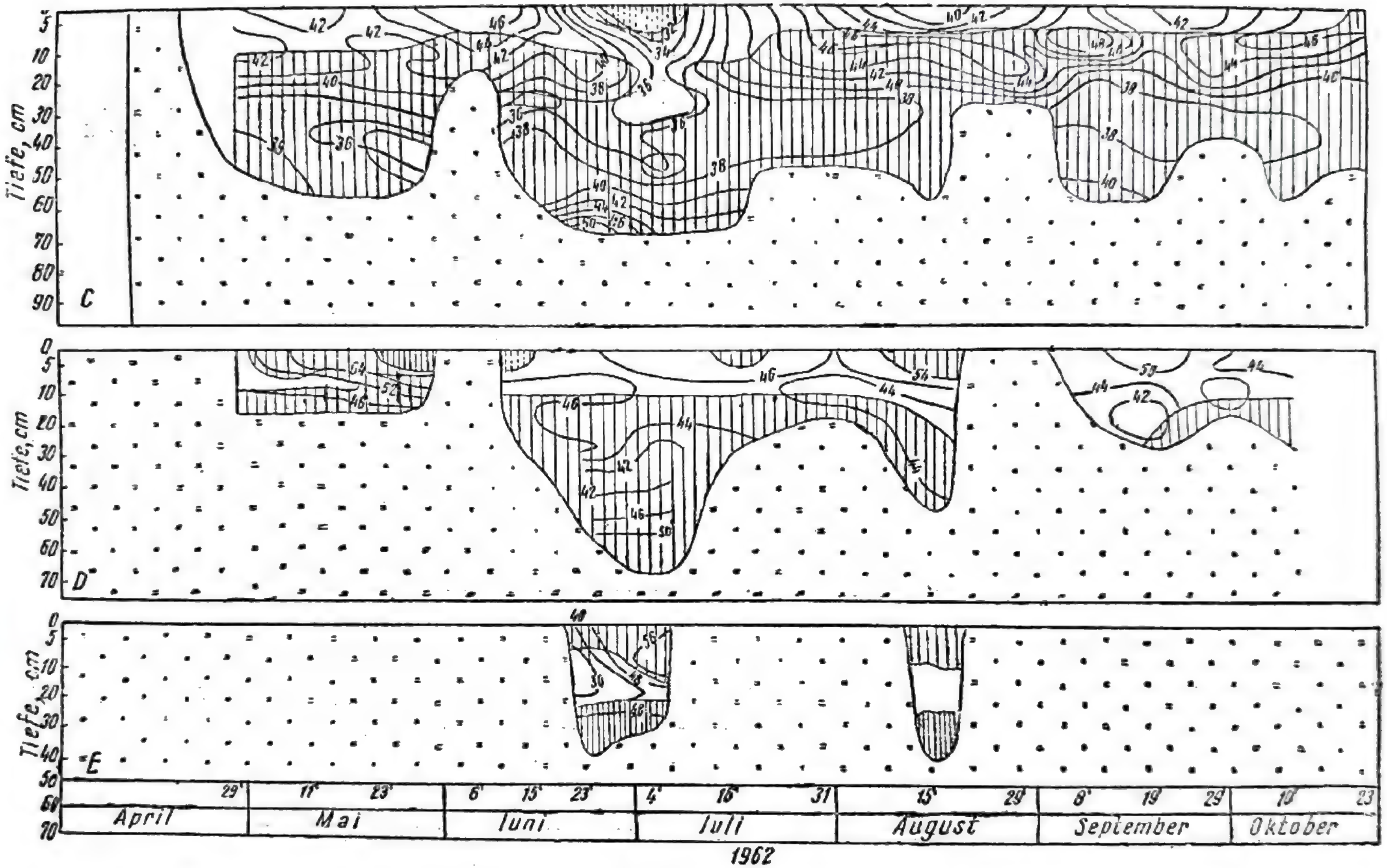

Abb. 3. Feuchtigkeitschronoisopleten der unvernässten und vernässten Auеböden im Tal des Moskwa-Flusses im feuchten Jahr 1962 (Die Feuchtigkeit in Prozent und Kategorien). Böden: *A* — schwerlehmige körnige Rasenböden; *B* — tonige tiefpseudovergleyte körnige Rasenböden; *C* — schwerlehmige mässig pseudovergleyte körnige Rasenböden; *D* — tonige stark pseudovergleyte körnige Rasenböden; *E* — Anmoor. Kategorienbezeichnungen sind dieselben (Abb. 2).

Tabelle 1

Der Einfluss des Vernässungsgrades der Rasenpodsole und Aueböden mit feiner mechanischer Zusammensetzung auf ihre landwirtschaftliche Nutzung im unentwässerten Zustand

Bodenname und Vernässungsgrad	Tiefenlage der stabilen Vergleyungsmerkmale	Vorhandensein und Tieflage der Staunässe in der Vegetationsmitte		Landwirtschaftliche Nutzung im natürlichen Zustand (ohne Entwässerung)	
		in feuchten Jahren	in (nach Niederschlagsmenge) trockenen und mittleren Jahren	in (nach Niederschlagsmenge trockenen und mittleren Jahren	in feuchten Jahren
Rasenpodsole					
Rasenpodsole nicht vernässt	Fehlen im Bereich der oberen (1,5 m) Bodenschicht			Der Anbau aller Kulturen ist möglich	
Rasenpodsole tief pseudovergleyt	Vergleyungsflecken ab 100 cm Tiefe; im gesamten Profil zahlreiche Eisenmangankonkretionen	fehlt	fehlt	Der Anbau aller Kulturen ist möglich	Der Anbau aller Kulturen ist bei Verwendung der den Abfluss fördernden agrotechnischen Massnahmen möglich Im Fall der Vergleyung in 1,0—1,3 m Tiefe ist die Entwässerung der Obstgärten notwendig
Rasenpodsole mässig pseudovergleyt	Vergleyungsflecken bis 30—40 cm Tiefe und ab 70—80 cm	Staunässe bis 30—40 cm u. ab 70—80 cm Tiefe	fehlt oder ab 120—130 cm Tiefe	Man kann Hafer, Kohl, Flachs, Turnip, Steckrübe, Futterrübe, Futterbohne, Gräser anbauen	Man kann Timotheegras, schwedischen Klee anbauen

Rasenpseudogley	Vergleyung im gesamten Profil, besonders intensive im Humushorizont	Staunässe bis 30—40 cm u. ab 60—70 cm. Tiefe. In einzelnen Jahren — Zusammenschluss der beiden Staunässeschichten	fehlt oder ab 80—130 cm Tiefe	Ohne Entwässerung ist der Anbau aller Kulturen unmöglich.	

Aueböden

körnige Rasenböden nicht vernässt	fehlen im Bereich der oberen (1,5m) Bodenschicht			Der Anbau aller Kulturen ist möglich	
körnige Rasenböden tiefpseudovergleyt	ab 90—100 cm Tiefe	90—100 cm	fehlt	Der Anbau aller Kulturen ist möglich	Der Anbau aller Kulturen ausser Obstbäumen ist möglich
körnige Rasenböden mässig pseudovergleyt	ab 50—60 cm. Tiefe	50—70 cm	130—140 cm	Man kann Hafer, Kohl, Turnip, Steckrübe, Futterrübe, Bohne, Gräser anbauen	Man kann schwedischen Klee, Glanzgras, Fuchsschwanz, Timotheegras, anbauen
körnige Rasenböden stark pseudovergleyt	ab 10—30 cm. Tiefe	20—30 cm	90—120 cm	Ohne Entwässerung kann man Fuchsschwanz, Glanzgras anbauen	Ohne Entwässerung ist der Anbau aller Kulturen unmöglich
Anmoor	Unmittelbar unter der Torfschicht	An der Oberfläche	40—50 cm	Ohne Entwässerung ist der Anbau aller Kulturen unmöglich	

bei der intensiven Bodenvernässung zu. Daraus geht hervor, dass, wenn die Feuchtigkeit der Staunässeböden ihrer Feldkapazität nahekommt, solche Verhältnisse eintreten können, bei denen die im Boden angelegte Dränage noch nicht wirkt und die Arbeit der Landmaschinen unmöglich ist. Der Erfolg der Meliorationsmassnahmen wird daher von dem Stand der Agrotechnik und der Gangbarkeit der landwirtschaftlichen Maschinen bestimmt.

Die Meliorationseigenschaften der Staunässeböden hängen mit ihren chemischen Eigenschaften und, innerhalb des erwähnten Gebietes, mit den Migrations- und Anhäufungsbesonderheiten des Eisens zusammen. Die hohen Mengen von auf Wasserscheiden eluviiertem Eisen gelangen zu den Flussauen. In Aueböden nimmt im Unterschied zu Landböden die Konzentration von Eisen mit dem Vergleyungsgrad zu (Zaidelman und Ogleznew, 1963).

Der hohe Gehalt an Eisen und oft auch Kalzium, Besonderheiten der biologischen Vorgänge, bewirken in Aueböden die Bildung einer wasserstabilen Struktur. Mit den günstigen Struktureigenschaften der Aueböden hängt eine Reihe von wichtigen Meliorationseigenschaften zusammen. Die Beständigkeit der Maulwurfdräns ist von der Wasserstabilität der Aggregate abhängig (Zaidelman, 1959). Bei der gleichen mechanischen Zusammensetzung funktionieren daher Maulwurfdräns oft lange auf Aueböden und sind ganz unstabil auf Rasenpodsolen (Zaidelman, 1963a). Unabhängig von der mechanischen Zusammensetzung ist die Podsolierung der Böden eine der wichtigsten Ursachen der Unhaltbarkeit der Maulwurfdräns. Deshalb ist die Maulwurfdränage auf diesen Böden von so kurzer Dauer, dass ihre Errichtung unrentabel ist. In Aueböden bleiben die Maulwurfdräns gewöhnlich im Laufe längerer Zeit unverändert.

Die Vergleyung ändert die Wasserdurchlässigkeit der Rasenpodsole nur wenig. In untersuchten unvernässten und vernässten Rasenpodsolen schwankte die Wasserdurchlässigkeit der Oberfläche im Bereich 0,08—0,12 m/24 Std. Die Durchlässigkeit unvernässter Aueböden ist viel höher als jene von pseudovergleyten (2,0—2,5 in unvernässten; in tiefpseudovergleyten — 0,4; in mässig pseudovergleyten — 0,2; in stark pseudovergleyten — 0,09 m/24 Std.). Die Entwässerung rief keine schroffe Veränderung der Durchlässigkeit der Rasenpodsole hervor. Die Wasserdurchlässigkeit der vernässten körnigen Aueböden kann sich hingegen von jenen der unvernässten sehr stark unterscheiden. Diese Darstellung geht zum Teil daraus hervor, dass die Menge der wasserstabilen Aggregate nach Austrocknung mit dem Vernässungsgrad stark zunimmt und zwar um so stärker je mehr vergley der entsprechende Horizont war. In vernässten Rasenpodsolen nimmt hingegen mit dem Vergleyungsgrad die Dispergierung der Aggregate zu. Daraus ergibt sich, dass bei gleichartiger Vernässung und mechanischer Zusammensetzung die Entwässerung der Aueböden in kürzerem Zeitabschnitt unter Verwendung von weniger intensiven Massnahmen erreicht werden kann als die Entwässerung der Rasenpodsole.

Angaben über die Veränderung der physikalischen Eigenschaften der Böden mit verschiedener Genese nach der Entwässerung wurden von Meljauskas (1963), Andrejauskaite (1961), Lutz (1960) und anderen Verfassern erhalten. Die gesammelten Materialien reichen jedoch für eine begründete Voraussage dieser Veränderungen bei der Meliorationsprojektierung nicht aus.

Zur Zeit werden viele Entwässerungsfragen noch ohne Berücksichtigung bodengenetischer Besonderheiten gelöst, es gibt aber alle Gründe, anzunehmen, dass die Ausrichtung und der Erfolg der Meliorationsmassnahmen in hohem Masse davon abhängen, inwieweit die durch die Genese der Nassböden bedingten spezifischen Besonderheiten untersucht und berücksichtigt sind.

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ZUSAMMENFASSUNG

Es wird eine Klassifikation der vernässten Böden zu Meliorations-und landwirtschaftlichen Nutzungszwecken vorgelegt, unter Zugrundelegung von Untersuchungen über den Wasserhaushalt und die Vegetationsverhältnisse. Es werden desgleichen die Versuchsbefunde hinsichtlich des Einflusses der bodenbildenden Prozesse (Podsolierung und Vergleyung) auf die Durchlässigkeit des Bodens besprochen.

SUMMARY

For melioration and agronomical purposes of water logged soils a classification is presented based in the research of water regime und vegetation conditions. Experimental results concerning the influence of soil-forming processes (podsolization and gleying) on soil permeability are also discussed.

RÉSUMÉ

On présente, aux fins de l'amélioration agricole, une classification des sols à excès d'humidité, en tenant compte des recherches sur le régime de l'eau et les conditions de la vegetation. De même, on discute les résultats expérimentaux concernant l'influence des processus pédogénétiques (podzolisation et gleyification) sur la perméabilité du sol.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

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L'INFLUENCE DU DRAINAGE DES SOLS À PSEUDOGLEY SUR LA CROISSANCE DES ESPÈCES FORESTIÈRES

IOAN Z. LUPE, MIHAI STRÎMBEI, VALER DONCA [1]

Les recherches concernant le desséchement du chêne dans les forêts aux inondations temporaires et aux sols à pseudogley, situées au nord-ouest de la Transylvanie et dans les Souscarpates de la Valachie ont montré que, dans des conditions de défeuillaisons intenses et répétées, le desséchement du chêne se manifeste plus fortement sur les superficies où les inondations sont prolongées (INCEF, 1961, 1962; Lupe, 1963). D'autre part, on a constaté que la croissance du chêne est plus prononcée dans les stations où les arbres disposent de beaucoup d'eau. Dans cette situation se pose le problème de l'opportunité du drainage (s'il est nécessaire ou non) comme moyen préventif contre le desséchement du chêne et, en cas affirmatif aussi le problème de l'influence du drainage sur la végétation ligneuse de ces forêts et spécialement sur la croissance du chêne.

Afin de préciser l'influence du drainage sur la végétation et sur la croissance de la forêt, on a organisé trois surfaces expérimentales à drainage par fossés du III-ème ordre ayant une profondeur de 30 à 40 cm et une largeur de 100 cm, à des distances de 12,5; 25; 50 et 100 m l'un de l'autre, sur des superficies rentrant dans le réseau de drainage du I^{er} et du II^{ème} ordre, l'éloignement entre les fossés étant dans ce réseau de 400 jusqu'à 500 m. On a aménagé ainsi une superficie expérimentale sur laquelle on a provoqué des inondations artificielles pendant 40, 60 et 90 jours par an, pendant un laps de temps qui varie d'une à trois années consécutives; le drainage intense et les inondations ont été combinés avec des défeuillaisons artificielles d'intensité variable.

La première de ces superficies expérimentales de drainage (fig. 1) est située dans une chênaie à chêne pédonculé, âgée de 65 à 70 années; la deuxième (fig. 2) et la troisième — à inondation, à défeuillaison et à drainage intense — dans une chênaie de 25 à 30 années et la quatrième dans une plantation récente, pratiquée en même temps que le creusemment des fossés.

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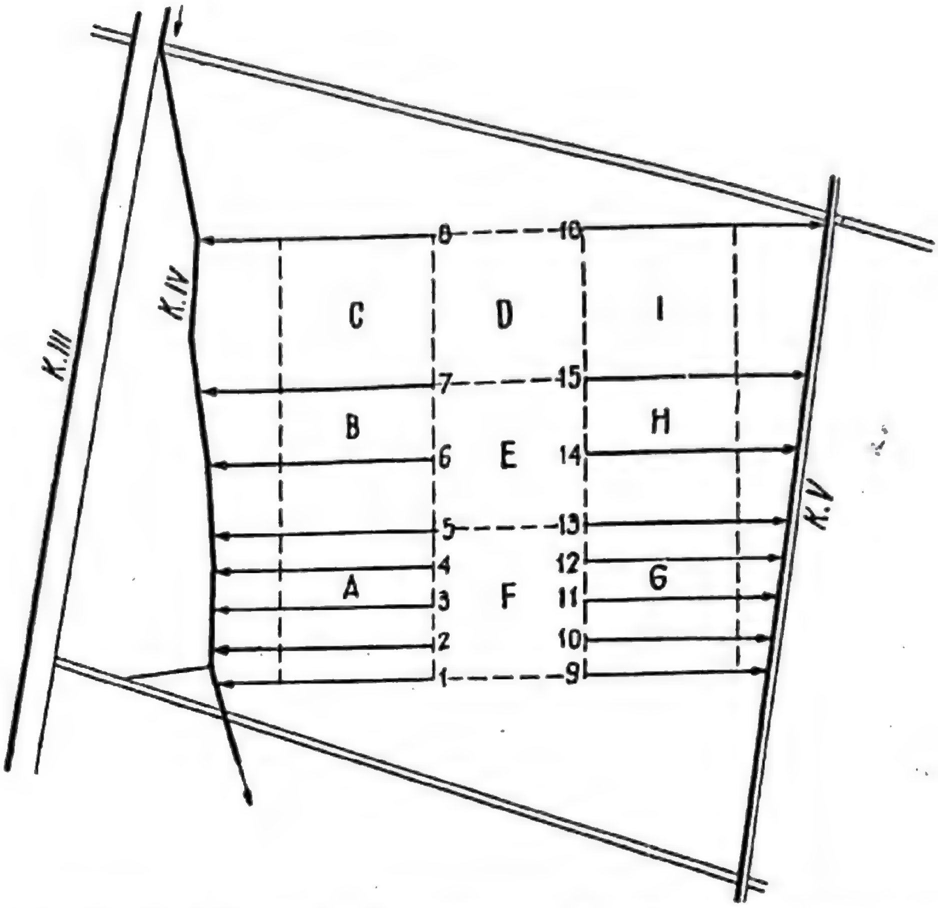

Fig. 1. Esquisse de la Ière surface expérimentale de drainage, située dans une chênaie âgée de 65 à 70 années : *K* — fossés de drainage de IIème ordre; *1* à 16 — fossés expérimentaux de IIIème ordre; *A,B,C,G,H, I* — parcelles expérimentales drainées; *D,E,F* — parcelles témoin; ... limites des parcelles expérimentales.

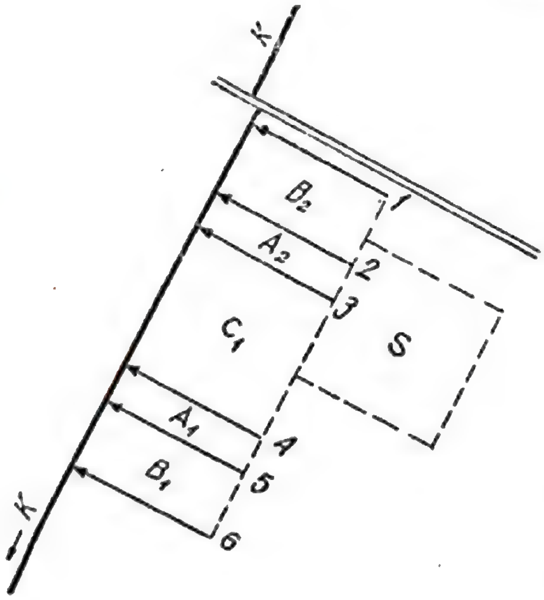

Fig. 2. Esquisse de la IIème surface expérimentale de drainage, située dans une chênaie de 30 années. *K* — fossé de IIème ordre; *1* à *6* — fossés de IIIème ordre; *A,B,C* — parcelles drainées; *S* — parcelle témoin ;...limites des parcelles expérimentales.

Sur toutes les superficies les sols sont des sols bruns à pseudogley, à texture argileuse (avec plus de 50% d'argile), ayant une porosité de 40—42%, qui ont, à une profondeur de 40 à 50 cm, un horizon argileux compact, pratiquement imperméable, lequel retient les eaux d'infiltration (eaux gravitationnelles) dans les couches supérieures, provoquant l'inondation temporaire, la podzolisation et la pseudogleyfication du sol.

Dans le présent rapport on donne les résultats du drainage, obtenus sur les parcelles expérimentales, pendant les premières années après le creusement des fossés.

L'élimination des eaux superficielles a été observée dans 10 points de contrôle situés dans les parcelles témoin comprises dans les superficies expérimentales, et dans une microdépression non comprise dans ces superficies. Dans ces points on a effectué aussi, à l'aide de sondages périodiques, des observations sur le drainage en profondeur dans des conditions différentes de microrelief :

— microdépressions (les points nr. 1 et 10) ;

— nanodépressions et terrain horizontal, sans écoulement (les points nr. 2 à 5) ;

— terrains presque horizontaux à écoulement très faible (les points nr. 6 à 9).

Le drainage vertical des eaux gravitationnelles a été observé à des distances de 5, 10, 15, 25, 35 et 50 m des fossés tant à l'aide de puits permanents, selon la méthode d'Hervé Magnon, que par des sondages instantanés, pratiqués 2 à 4 heures avant d'effectuer les observations (mesurages) sur le niveau d'eau.

L'influence de l'élimination des eaux superficielles et celle du drainage en profondeur des eaux gravitationnelles sur la végétation de la forêt ont été établies par des observations sur les modifications survenues pendant une période de trois années dans la couche herbacée et dans le semis naturel de chêne.

Ces observations ont été effectuées par l'inventaire périodique des plantes et par des mesurages de la croissance en hauteur des jeunes cultures et de la croissance en grosseur, pratiqués sur des échantillons extraits à l'aide du foret de Pressler dans les peuplements de 30 et 70 années.

L'élimination des eaux superficielles et le drainage du sol en profondeur sur les parcelles témoin et sur les superficies, comprises entre les fossés experimentaux situés à differentes distances, sont présentés dans les diagrammes des figures 3 et 4.

Dans ces diagrammes on voit que dans les microdépressions et sur les superficies pratiquement privées d'écoulement (nanodépressions, terrains horizontaux) l'eau reste à la surface du sol jusqu'à la mi-avril ou encore en mai, puis elle baisse presque brusquement, dans un laps de temps de 1 à 2 semaines, jusqu'à la profondeur de 50 à 60 cm et n'augmente que de très peu dans les périodes très pluvieuses. Sur les terrains horizontaux et en pente très douce, à faible écoulement, les eaux disparaissent de la surface au moment de la fonte des neiges et restent dans le sol près de la surface, à une profondeur de 8 à 12 cm, jusqu'à l'époque du reverdissement de la forêt

— à la mi-avril — quand elles baissent brusquement jusqu'à la profondeur de 40 à 60 cm, ou davantage, et ne s'élèvent que très peu pendant les périodes des pluies abondantes et prolongées (13 à 15 juin).

Entre les fossés de drainage, les eaux ne restent pas à la surface. En profondeur, elles sont drainées graduellement par rapport aux distances

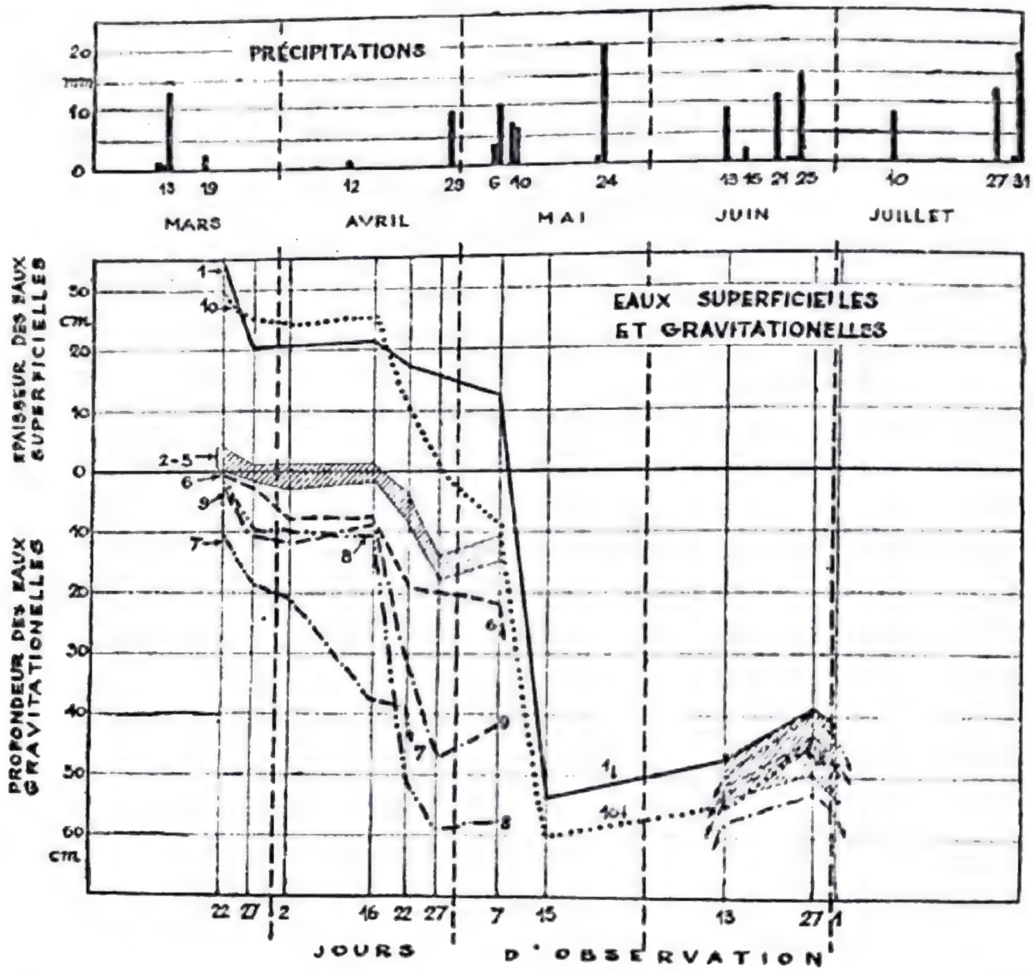

Fig. 3. Précipitations et drainage des eaux superficielles et gravitationnelles : *1* à *10* — courbes représentant la variation des niveaux d'eau pour les 10 points de contrôle.

jusqu'aux fossés et à la texture et la structure du sol. En général, jusqu'au moment du reverdissement de la forêt, le niveau de ces eaux suit la courbe classique de drainage à fossés parallèles (fig. 4). Après le reverdissement de la forêt, le niveau des eaux gravitationnelles baisse brusquement, même entre les fossés, au-dessous du niveau de base des fossés, de manière que l'aspect de la courbe de drainage devient irrégulier et n'est plus celui de la courbe classique, étant déterminé par l'hétérogénéité de la structure du sol et par la quantité d'eau absorbée par la forêt. Ici encore le niveau des eaux gravitationnelles ne s'élève que très peu pendant les périodes pluvieuses plus prolongées. Le drainage en profondeur augmente avec l'accour-

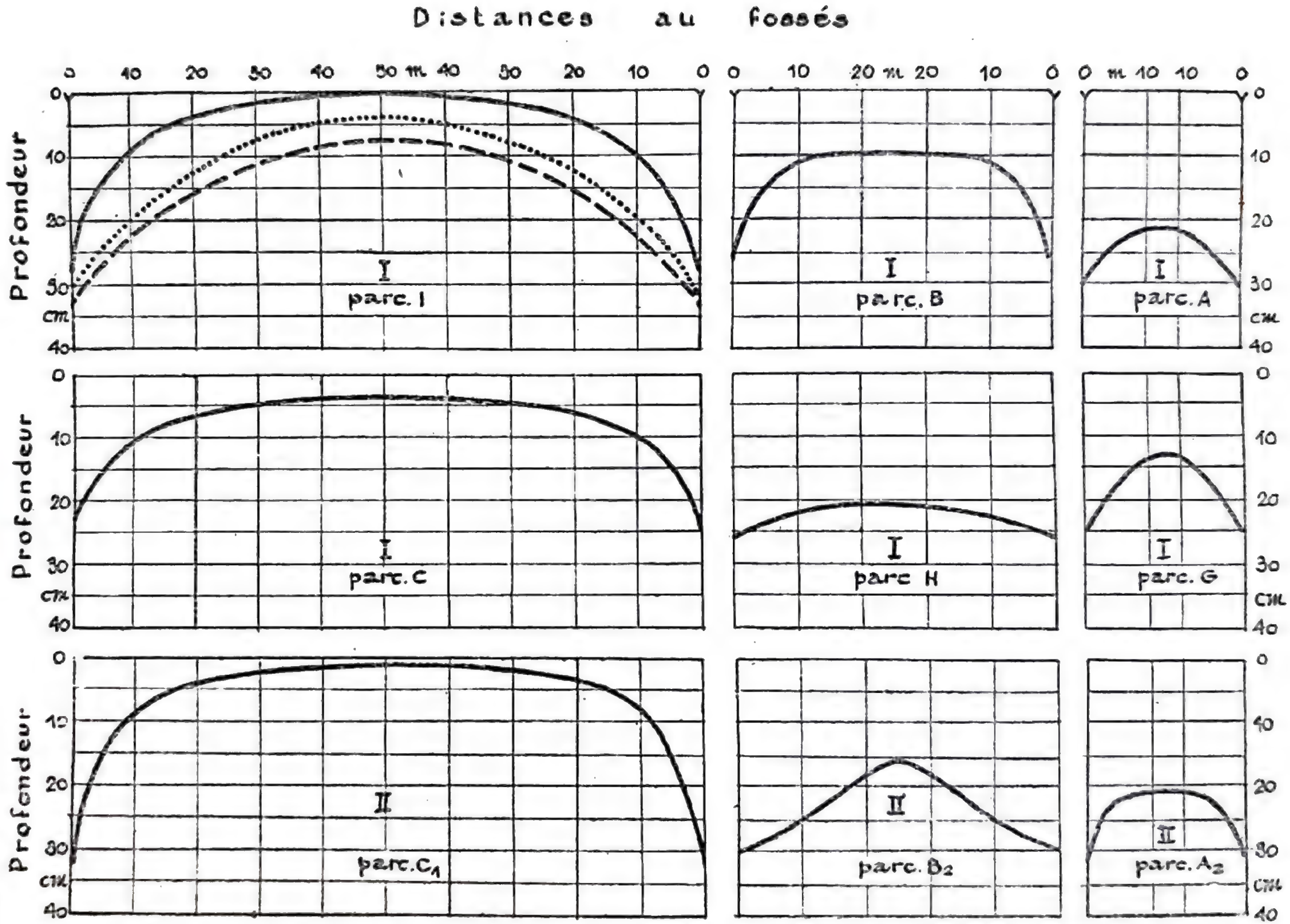

Fig. 4. Courbes du drainage en profondeur avant le reverdissement de la forêt, entre les fossés à des distances de 25, 50 et 100 m. — 22. III.1963 ;....27. III.1963 ; — — 6.IV.1963.

cissement de la distance aux fossés, respectivement avec celui de la distance entre les fossés.

L'élimination des eaux superficielles et le drainage du sol en profondeur se sont très clairement reflétés dans la végétation et dans la croissance de la forêt, dès les premières trois années écoulées après le creusement des fossés.

Dans les chênaies de 30 et 70 années, la consistance de la couche antérieurement haute et dense de *Carex riparia Curt* dans les dépressions a diminué; les plantes sont devenues chétives et peu développées. Les touffes grandes et denses de *Juncus effusus L.* étaient moins fréquentes et moins développées, devenant très chétives et clairsemées, et se résumant souvent à quelques brins d'herbe. Le tapis dense d'*Agrostis alba L.* a été aussi beaucoup réduit en densité et en épaisseur, étant dissimulé à la surface du sol sous les herbes méso-hydrophiles, développées à ses dépens.

En conséquence, au lieu des espèces caractéristiques pour les sols marécageux: *Carex riparia Curt.*, *Juncus effusus L.*, *Agrostis alba L.*, des espèces mésophiles, comme *Dactylis glomerata L.*, *Trifolium pratense L.*, *Prunella vulgaris L.* etc. ont fait leur apparition. Le semis naturel de chêne, qui avant le drainage périssait toujours sous les eaux d'inondation, stagnantes jusqu'à la fin du printemps ou jusqu'au début de l'été, s'est entièrement maintenu après le drainage, témoignant d'une croissance normale. Il y a probabilité qu'après un laps de temps plus prolongé à la suite du drainage, des modifications manifestes se produisent dans la faune et la flore interne et dans la genèse du sol.

Dans les plantations nouvelles la couche herbacée présente les mêmes tendances de succession; la substitution des espèces hydrophiles par des espèces méso-hydrophiles. Outre cela, quelques-unes des espèces ligneuses sensibles à l'excès d'humidité du sol ont survécu et ont réalisé des croissances plus grandes dans les surfaces limitées par les fossés de drainage qu'en régime naturel, sans drainage. Parmi ces espèces on peut citer en premier lieu les espèces résineuses: l'épicéa, le pin commun, le mélèze, le Douglas; et des arbres à feuilles: le charme et le noisetier. Le chêne et les peupliers n'ont pas montré de différences sensibles entre les parcelles drainées et non-drainées en ce qui concerne la réussite, mais plutôt la croissance.

Dans la chênaie de 30 années, on a réalisé, dans le laps de temps de trois années après le drainage, sur les superficies limitées par les fossés, une augmentation de croissance radiaire de 0,9 à 1,2 mm (11,5—14,8%), par comparaison à la croissance des dernières années précédant le drainage. Les augmentations de croissance sont significatives et très significatives. Sur la parcelle témoin on n'a observé aucune différence entre la croissance avant et après le drainage (tableau 1). Après le creusement des fossés, sur les surfaces comprises entre les fossés on a enregistré une augmentation de la croissance radiaire de 1,1 à 2,4 mm (15,5—33,8%), par comparaison à la croissance de la même période, obtenue sur la parcelle-témoin moins drainée.

Dans la chênaie de 70 années, on a réalisé de la même manière, dans un laps de temps de trois années après drainage, une augmentation de la croissance radiaire, significative jusqu'à très significative, de 1,1 à 1,2 mm

Tableau 1

Influence du drainage sur la croissance du chêne dans les premières 3 années après le creusage des fossés

Situation des surfaces	Distances jusqu-aux fossés	Epaisseur de 3 anneaux annuels A avant le drainage	Epaisseur de 3 anneaux annuels B après le drainage	Différences entre B et A			Différences B par rapport au régime naturel *		
	m	mm	mm	mm	%	Sign.	mm	%	Sign.
I. Chênaie âgée de 65 à 70 années									
Régime naturel *	—	4,9±0,3	5,0±0,4	0,1	2,0	*	—	—	—
Dans le réseau de III-ème ordre	0—10	4,5±0,2	5,7±0,3	1,2	26,7	***	0,7	14,0	*
	10—20	4,8±0,2	6,0±0,2	1,2	25,0	***	1,0	20,0	*
	20—30	4,8±0,2	6,0±0,2	1,2	25,0	***	1,0	20,0	*
	30—50	5,1±0,3	6,2±0,4	1,1	21,6	*	1,2	24,0	*
II. Chênaie âgée de 25 à 30 années									
Regime naturel *	—	7,1±0,3	7,1±0,3	0,0	0,0		—	—	
Dans la réseau de III-éme ordre	0—10	8,1±0,3	9,3±0,3	1,2	14,8	**	2,2	31,0	***
	10—20	7,2±0,3	8,2±0,3	1,0	13,9	*	1,1	15,5	*
	20—30	7,9±0,4	8,8±0,4	0,9	11,5	*	1,7	24,0	**
	30—50	8,3±0,3	9,5±0,4	1,2	14,5	**	2,4	33,8	***
III. Chênaie âgée de 25 à 30 années, inondée et drainée intensivement									
Regime naturel *		7,1±0,2	7,7±0,2	0,6	8,5	*	—	—	
Inondée 90 jours par an, 3 années de suite		7,3±0,2	7,7±0,2	0,4	5,5	*	0,0	0,0	
Drainée intensivement		6,0±0,2	7,9±0,3	1,9	31,7	***	0,2	2,6	**

* Dans le résseau de I-er et II-ème ordre.

(21,6—26,7%) entre les fossés de drainage, par comparaison à la croissance des dernières trois années précédant le drainage. Comme dans le premier cas, on n'a enregistré sur la parcelle témoin non plus de différences significatives, entre la croissance avant et après drainage. Après le creusement des fossés, on a enregistré ici une augmentation de la croissance radiaire, sur les superficies limitées par les fossés, de 0,7 à 1,2 mm (14,0—24,0%), par comparaison à la croissance obtenue sur la parcelle témoin pendant la même période.

Il faut observer que l'épaisseur des anneaux annuels présente une grande variation (les coefficients de variation se situent entre 15 et 40%); la précision est située fréquement, entre 95 et 97%) ($s_{\bar{x}}\,\% = 3$—5%), et plus rarement entre 93 et 94% ($s_{\bar{x}}\,\% = 6$—7%).

Sur la superficie experimentale à inondation-drainage, on n'a pas enregistré d'augmentation de croissance pendant les trois dernières années, par comparaison aux trois années antérieures, comme sur la parcelle à drainage intense. Sur cette parcelle, l'augmentation de croissance est très significative et se rapproche, par sa valeur, de l'augmentation enregistrée dans le peuplement du même âge situé dans la bande de terrain intensivement drainé, allant des fossés jusqu'à 10 m de ceux-ci. Cette augmentation est de 1,9 mm (31,7%). Dans ce peuplement, sur la surface inondée pendant trois années consécutives pour un laps de temps de 90 jours durant la période de végétation, les croissances radiaires sont pratiquement égales aux croissances survenues sur la superficie maintenue en régime naturel (sans drainage). Pendant les dernières années, les croissances sur les trois parcelles experimentales sont presque égales.

CONCLUSIONS

1. Le drainage en profondeur des sols à pseudogley, par fossés de 35 à 40 cm de profondeur, se manifeste à une profondeur de 5 à 30 cm, et seulement à des distances de 10 à 25 m des fossés. Ce drainage est présent seulement jusqu'au reverdissement de la forêt. Après le reverdissement le niveau des eaux gravitationnelles baisse presque brusquement au-dessous du niveau du fond des fossés, de manière que ces fossés n'exercent plus aucune influence. Les eaux superficielles sont éliminées des terrains horizontaux et à pente légère intégralement et immédiatement après la fonte des neiges et après les pluies, mais se maintiennent pendant une période de 15 à 20 jours, jusqu'au moment du reverdissement de la forêt, sur les terrains dépressionnaires privés d'écoulement.

2. L'élimination des eaux superficielles et de celles qui imbibent la couche supérieure du sol donne lieu à des changements dans la composition et dans la structure de la couche herbacée; la flore hydrophile est limitée et remplacée pour la plupart par des plantes méso-hydrophiles. La densité et l'épaisseur du tapis herbacé diminuent et les plantes qui forment le semis naturel se maintiennent et poussent de manière normale.

3. Dans les plantations nouvelles, les espèces forestières sensibles à l'inondation, principalement les espèces résineuses (l'épicéa, le pin commun,

le mélèze, le Douglas) et des espèces à feuilles caduques (le charme et le noisetier) se maintiennent et poussent mieux sur les surfaces drainées qu'en régime naturel. Le chêne et les peupliers sont peu sensibles au drainage en ce qui concerne la réussite, mais plus sensibles en ce qui concerne la croissance.

4. La croissance radiaire du chêne a enregistré des augmentations significatives jusqu'à très significatives sur les terrains drainés, par comparaison aux croissances enregistrées sur les terrains non-drainés, tant sur les mêmes superficies, comparées avant et après drainage, ainsi que sur superficies drainées, comparées à des parcelles témoin non drainées, ou à des superficies inondées artificiellement.

Il résulte donc que le drainage des sols à pseudogley est profitable à la forêt, en ce qui concerne d'une part la régénération naturelle et artificielle et l'amélioration du sol et de la forêt, et de l'autre la croissance des arbres, c'est à dire la productivité et la production de la forêt.

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RÉSUMÉ

Les recherches expérimentales concernant l'influence du drainage des eaux gravitationnelles de chênaies aus sols à pseudogley, situées dans le nord-ouest de la Roumanie, à l'aide de fossés de drainage de IIIème ordre ayant une profondeur de 30 à 40 cm et placés à des distances de : 12,5 ; 25 ; 50 et 100 m l'un de l'autre, compris dans le réseau de Ier et de IIème ordre (fig.1 et 2), ont montré que le drainage varie avec la configuration du terrain, l'état de la forêt, les distances jusqu'aux fossés et l'espacement entre les fossés (fig. 3 et 4).

Le drainage a eu pour consequence : la diminuation de la flore herbacée et la substitution des plantes hydrophiles par des plantes mésophiles et mésohydrophiles ; le maintien en vie et le développement normal du semis naturel du chêne et des jeunes plants des espèces sensibles à l'inondation et l'augmentation de la croissance radiaire du chêne de 14 à 34 % (tableau 1).

SUMMARY

Experiments on the influence of the drainage of surface water of gley soils on forest vegetation were carried out in the north-west of Transylvania with ditches of the third order, 30—40 cm deep, separated by distances of 12.5, 25, 50 and 100 m and included in the network of the first and second order.

Figures 1 and 2 show that drainage is different according to land forms, to the state of the forest, to the distances from the ditches and to ditch spacing.

The drainage resulted in a decrease in the herbaceous species and the substitution of hydrophile plants by mesophile and mesohydrophile plants, in the maintenance and normal development of the oak seeding as well as of the young plants belonging to the species sensitive to floods and in a radial increase in oak trees from 14 to 34% (table 1).

ZUSAMMENFASSUNG

Versuche in Zusammenhang mit der Feststellung des Einflusses, den die Entwässerung der Pseudogleyböden auf die Waldvegetation ausübt, sind in den Eichenwäldern im Nordwesten Siebenbürgens durchgeführt worden, unter Einrichtung von Entwässerungsgräben 3. Ordnung, 30 bis 40 cm tief und 12,5—25—50—100 m voneinander entfernt, in einem Netzwerk 1. und 2. Ordnung.

Aus den Abbildungen 1 und 2 ist ersichtlich, dass die Entwässerung mit der Geländebeschaffenheit, dem Waldzustand, der Entfernung bis zu den Gräben und dem Abstand zwischen den Gräben variiert. Die Entwässerung wirkte sich aus in einer Verminderung der Grasflora und einer Verdrängung der hydrophilen Pflanzen durch mesophile und mesohydrophile Pflanzen, in der Erhaltung und normalen Entwicklung der natürlichen Eichenaussaat, sowie der jungen gegen Uberschwemmung empfindlichen Pflanzenarten, als auch in der Zunahme des radialen Wachstums der Eiche von 14% zu 34 (Tafel 1).

DISCUSSION

K. SCHWARTZ (Deutsche Demokratische Republik). Die Entwässerung bestimmter Pseudogleytypen mit flachliegendem Verdichtungshorizont bereitet, infolge der hier geringen Wasserbewegung des Gravitationswassers, erhebliche Schwierigkeiten. Um was für Pseudogleyform handelt es sich bei Ihren Untersuchungen? Traten hier ähnliche Schwierigkeiten auf und wenn ja, welche Gegenmassnahmen lassen sich treffen?

I. LUPE. Il s'agit d'un pseudogley provoqué par les eaux de gravité provenant des précipitations. Aucune difficulté ne s'est présentée en ce qui concerne l'écoulement en surface, mais le drainage en profondeur est lent et se manifeste sur des distances relativement courtes à partir du drain (fossé de drainage).

FORESTRY ON FINE-TEXTURED SOILS WITH A HIGH GROUND-WATER TABLE

H. HOLSTENER-JØRGENSEN [1]

A considerable part of the Danish forests grows on clayey moraines from the last Glacial age. The localities prove to have a high ground-water-table, and the conditions of forestry are often rather bad. A number of investigations have therefore been made in these forests by the Danish Forest Experiment Station. The following is a brief report on the results of the investigations.

1. GROUND-WATER FLUCTUATIONS IN FOREST

At the investigations we have used simple and inexpensive methods. The movements of the ground-water-table were followed in wells like those shown in figure 1. These are open shafts bored with an earth auger with a 10 cm diameter. Such open earth shafts function excellently in rather clayey soil. They offer the advantage that the natural layers in the soil are not disturbed by digging. To secure the shaft and prevent the topmost humus layer from falling inpossibly in connexion with winter frost — a concrete socket pipe is placed into the mouth of the well with the socket resting on the surface of the ground. The distance to the ground-water-table is measured from the brim of the socket, which may be adjusted so that it is on a level with certain fixed points.

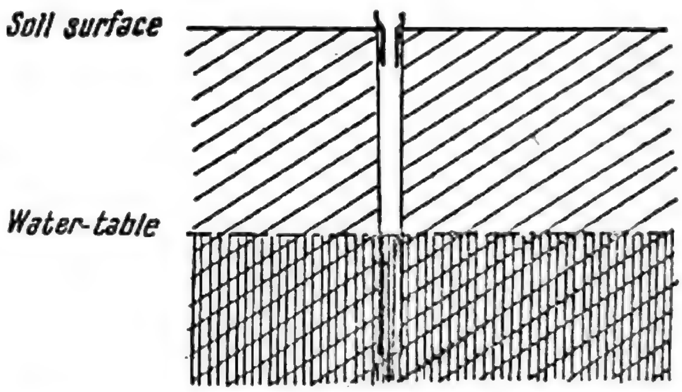

Fig. 1. Diagram illustrating the well arrangement used.

[1] The Danish Forest Experiment Station, DANEMARK.

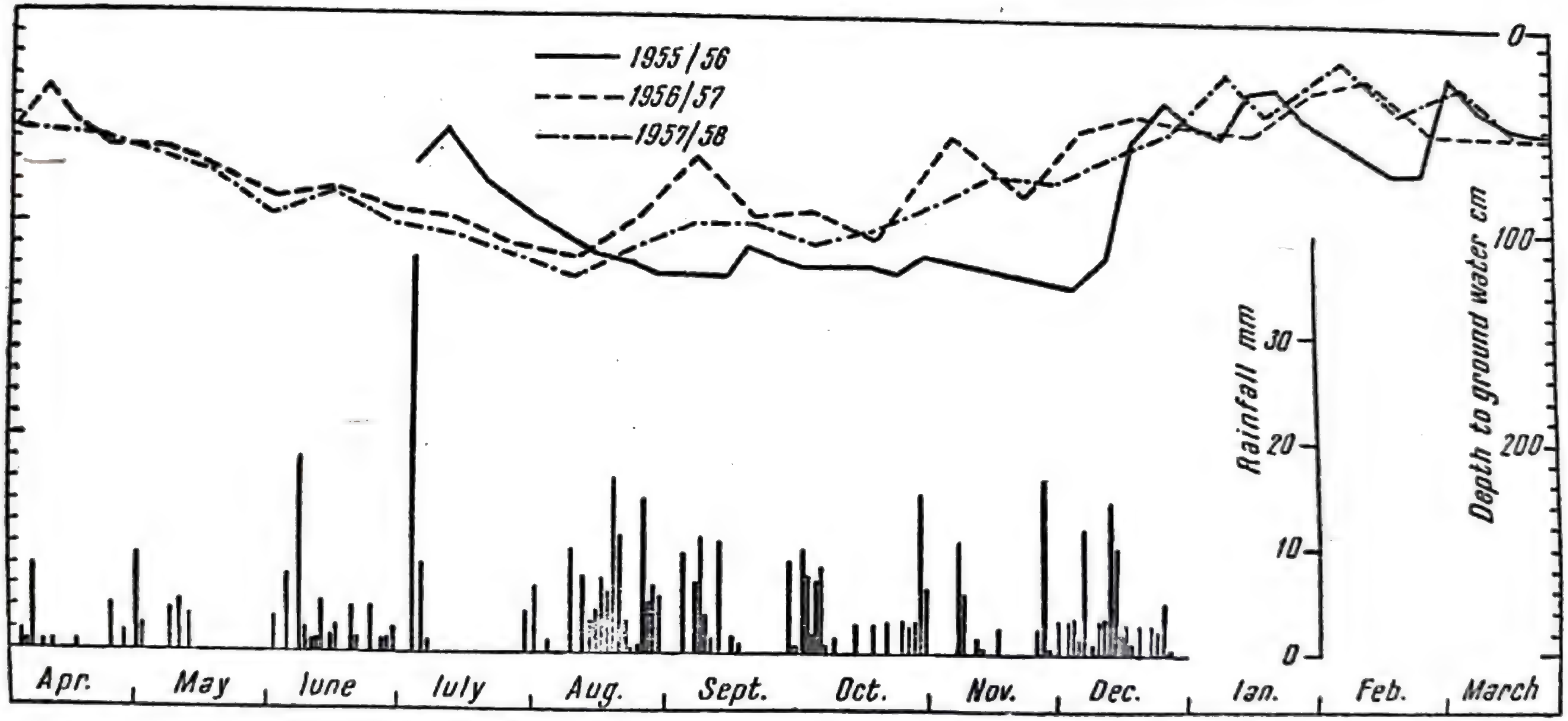

Fig. 2. Water-table fluctuations on a Norway spruce sample plot during three years. The daily rainfall in part of the year 1956 is marked in as columns.

Figure 2 shows the fluctuations of the ground-water-table through a period of three years in a 45-years-old Norway spruce stand (Holstener-Jørgensen, 1959a). The measurements were made with intervals of 14 days. It appears that the ground-water-table is high in the winter months (December to March). During the growing season the water sinks concurrently with the water consumption of the stand, and a new rise occurs when the soil is saturated during the autumn.

In figure 2 the precipitation in part of 1956 has been entered. A comparison of the precipitation columns and the water-table curve for 1956/1957 shows that a heavy precipitation at the beginning of July is not reflected in the ground-water curve. In June/July the evapotranspiration is heavy, and great quantities of ground-water are consumed. The heavy precipitation in July has not been sufficient to replace the evaporated water. In August there was again a heavy precipitation. The figure shows that at the second measurement in August the water-table has risen, and the rise continues until some time in September.

After the growing season the soil is saturated with water from above. When the profile is saturated to the ground-water-table, the ground-water rises. Usually the rise is completed within a short time, as under the soil conditions in question very few millimetres of precipitation are needed to bring about a heavy rise. The 1955/1956 curve in figure 2 illustrates such a sudden rise at about the middle of December.

The curves in figure 2 show a common feature in the months of January, February and March. They have the same lowest point. This point is at a depth of approximately 50 cm, and we have called it *"highest stable ground-water-table"* (*H.S.G.*).

Figure 3 shows the distribution of pores in a profile of the same sample plot. The ground-water is contained in the macropores. The bigger the pores and the greater their number, the freer will be the movement of the ground-water. The content of macropores is greatest in the upper layers, in the present case the topmost 40—50 cm. Our measurements show that in the mentioned stand the ground-water often rises, for instance, to 10 cm below the surface of the ground in moist, mild periods in the winter, but it quickly falls again to a depth of abt. 50 cm. This also applies to deciduous stands, which have no leaves and therefore have no evapotranspiration in the winter months. The explanation must be that the ground-water in the topmost 40—50 cm of the soil is quickly drained away sideways to the existing ditches. *H.S.G.* depends on the pore conditions in the soil and coincides approximately with the physical horizontal limits in the soil.

Examinations in a number of localities show that lowest water-table is correlated to the depth of the roots of the stand (Holstener-Jørgensen, 1959 a). From this follows that the lowest water-table, or a water-table in late summer, may be used as an index number for the depth of the roots. In a more comprehensive investigation we have exploited this experience (Holstener-Jørgensen, 1961). In the spring of 1959 wells were bored in 99 stands of various tree-species of various ages. The fluctuations of the water-table were followed during two years. The experiment included 26 beech

stands, 29 oak stands, 23 Norway spruce and sitka spruce stands, 10 ash stands and 11 stands of other tree-species.

The following summary is based on the measurements of 1959. The water-table on 21st April, 1959, was taken to represent *H.S.G.*, and the

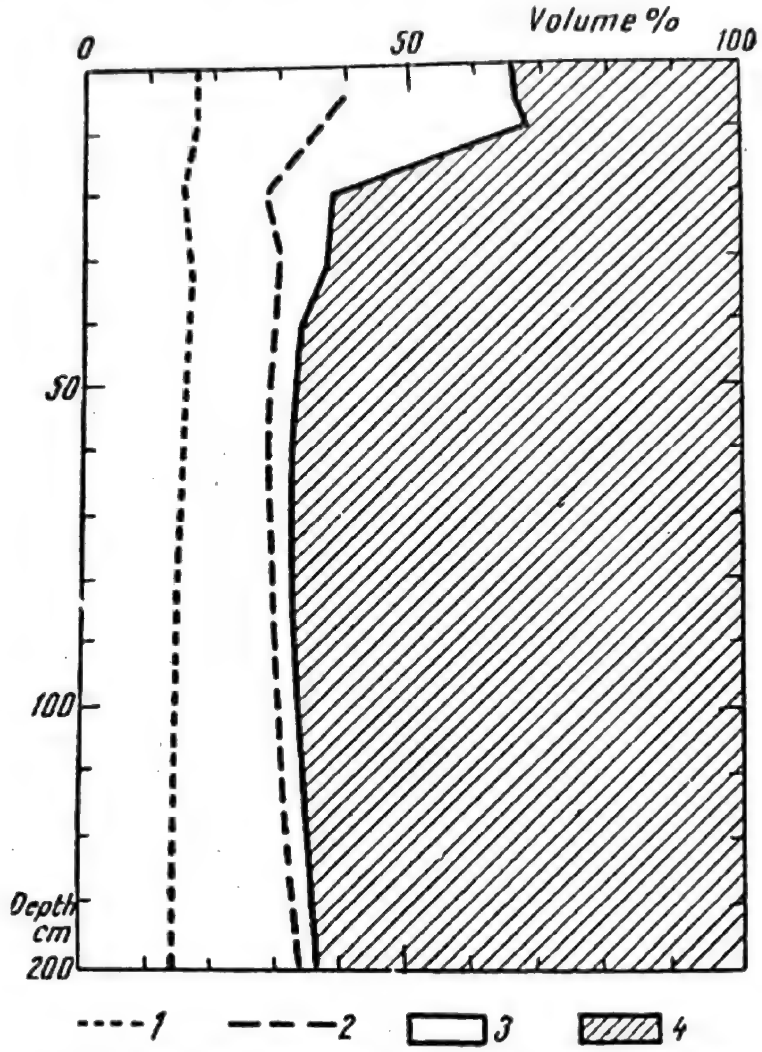

Fig. 3. Pore size distribution in one soil profile on the Norway spruce sample plot: *1*—vol. per cent at pF 4.2; *2*—vol. per cent at pF 2.0; *3*—total pore volume; *4*—soil particles.

water-table on 20th August, 1959, was used as a standard for lowest water-table.

It appears from the experiment that there is a difference between the tree-species. For all the tree-species the age of the stand is correlated to the depth to which the ground-water is lowered during the growing season. Figure 4 shows the correlation of age to the 20/8-water-table in oak stands. The correllation curve is an exponential function.

For two tree-species, viz. beech and Norway spruce, it could be demonstrated that the 21/4 -water-table was correlated to the 20/8 -water-table. Figure 5 illustrates the facts relating to beech.

A statistical analysis of the aggregate material gave the results shown in table 1.

Table 1

Result of statistical analysis

Forest species	Regression equation	Multiple correlation coefficient
Beech	$y = -98.45 + 89.07^{*} x_1 + 3.79^{***} x_2$	0.719***
Oak	$y = 28.42 + 150.66^{***} x_1 + 0.10 x_2$	0.608***
Norway spruce	$y = 31.82 + 63.16^{*} x_1 + 0.98^{***} x_2$	0.900***
Ash	$y = 81.66 + 185.72 x_1 - 2.80 x_2$	0.449

y — depth to water-table, cm, 20/8/1959.
x_1 — log age.
x_2 — depth to water-table, cm, 21/4/1959.
*, and *** indicate significance on the 5 per cent, 1 per cent and 0,1 per cent level.

As mentioned, the lowest water-table (in this case, the 20/8-water-table) depends on the depth of the rootage space. Consequently, the depth of the rootage space seems to increase with the age. Certain tree-species (beech and Norway spruce) develop a flatter rootage system with a higher *H.S.G.* Therefore it is no matter for surprise that the increment in beech stands is narrowly correlated to the *H.S.G.* (Holstener-Jørgensen, 1961).

2. THE EFFECTS OF SILVICULTURAL MEASURES ON THE GROUND-WATER FLUCTUATIONS

In soils like those examined the water-table fluctuations during the growing season are practically entirely a function of the water consumption of the trees. From this follows that any silvicultural measures which affect the water consumption of the trees will also affect the ground-water-table. The demonstration of such an influence is easiest and most reliable in connexion with heavy interventions, which, however, are also normal in forestal practice.

Figure 6 shows the ground-water curves for two years in a Bregentved locality (Holstener-Jørgensen, 1959b). In 1956 the area was still covered by 75-year-old beech with some undergrowth. The upper story had a volume of 401 m³/ha, whereas the lower story had a volume of 5 m³/ha. The figure shows how the closed stand lowers the water-table during the growing season.

In the winter of 1956/1957 the beech stand was clear-cut, and in the spring of 1957 the area was planted with Norway spruce. The 1957-curve

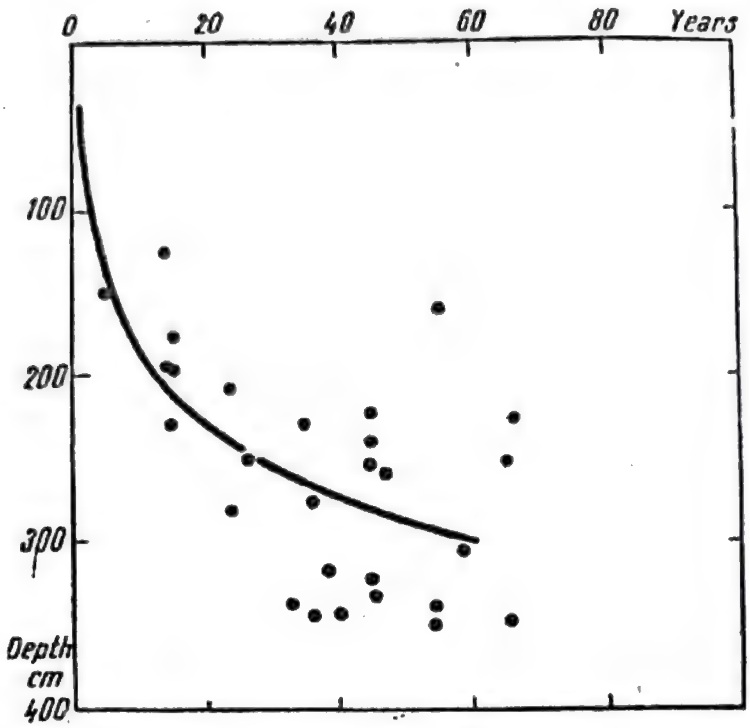

Fig. 4. The correlation between 20/8 depth to the water-table (cm) in oak stands and the ages of the stands. A computed exponential curve has been sketched in.

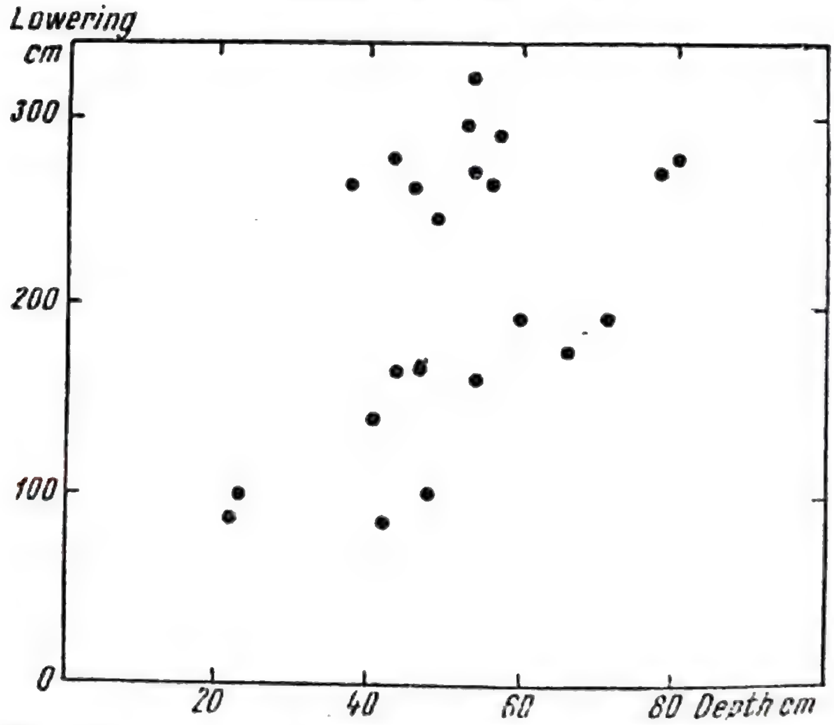

Fig. 5. The correlation between 21/4 depth to the water-table (abcissa, cm) and the lowering of the water-table from 21st April through 20th August in beech stands older than 30 years.

in figure 6 shows that the rich flora following the clear-cutting together with the newly planted Norway spruces are in no way able to lower the ground-water to the depths reached by the beech stand.

The experiment comprised four plots, each of about 0.7 ha. Two plots were maintained as checks, as mentioned one plot was clear-cut in the winter of 1956/57, and at the same time the last plot was shelterwood-cut. At the shelterwood-cutting the whole of the lower story and about one third of the upper story were removed. There is a total of 31 ground-water wells in the area. The average figure for the various groups of wells with correction for the changes from 1956 to 1957 in the controls shows that clear-cutting has raised the lowest water-table by 2 m, whereas shelter wood-cutting has raised the lowest water-table by 1 m. This, of course, is a very popular way of representing the facts.

Fig. 6 shows that in 1956 the rise of the water-table in the area started at the end of November and was completed at the end of December. After the clear-cutting the water already rose at the end of August. On an average, the rise to *H.S.G.* proved to be

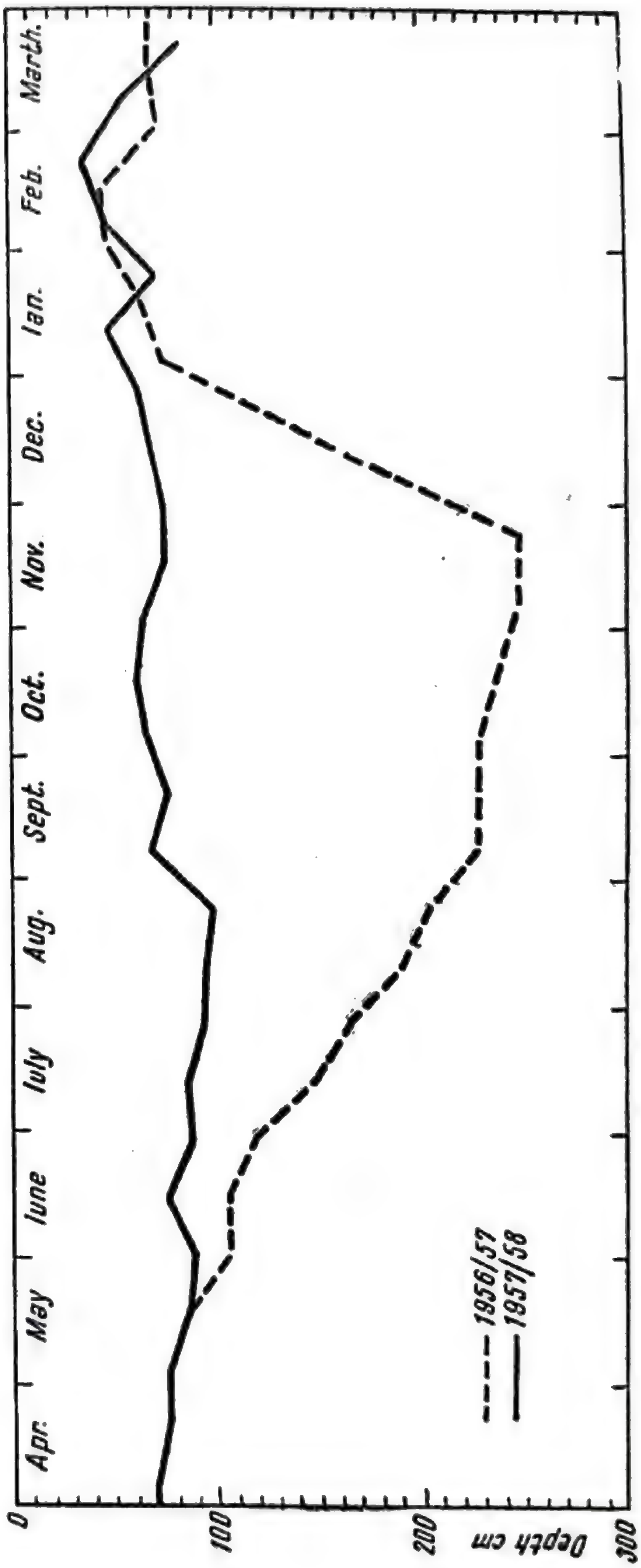

Fig. 6. Water-table fluctuations before and after clear-cutting of 75-years old beech stand.

completed 127 days earlier after clear-cutting and 81 days earlier after shelterwood-cutting.

The experiment shows that felling alters the water-table fluctuations. On this occasion I shall confine myself to pointing out a single pedologic aspect of this fact. The oxydation and reduction processes in the soil must be affected in the same way by the felling. Incidentally, there is no reason to believe that light felling should not have the same effect, although to a smaller extent.

3. THE EFFECTS OF SILVICULTURAL MEASURES ON THE GROWING CONDITIONS

It is well-known that flooding during the growing season may kill trees. The sensibility to flooding depends both on the species and on the age. Some species are more sensitive than others, and resistance to flooding increases with the age (see e.g. Kirwald, 1950; Hall and Smith, 1955; Ahlgren and Hansen, 1957).

When felling involves a higher water-table in the summer, it means that the depth of the rootage space is diminished. In ground-water-sensitive tree-species, such as beech, the deeper parts of the rootage system are drowned. In Denmark partial root death in connexion with thinning has often been observed in beech stands (e.g. Ladefoged, 1938). In shelterwood-cut stands the observation may often be made that the sheltering trees compete increasingly with the underplanted tree-species for the rootage space. In localities like those mentioned here this is no doubt due to an increased root formation in the top soil by the sheltering trees, a root formation which is more or less induced by the limitation of the depth of the rooting space. This undesirable root competition is the keener, the more trees have been removed by the shelterwood-cutting.

A heavy thinning followed by a rainy summer may prove a catastrophe to a beech stand. In the spring of 1960 a 116-year-old beech stand began to wilt. The crowns were scantily leafed, and the leaves small and yellowish. A close examination betrayed that the soil was clayey and that there was a high water-table. The increment had been low from 1957 onward. Two trees were overturned. All roots deeper than 10 cm below the surface had died. Moreover, all top-soil roots in a greater distance than 50 to 200 cm from the base of the stem were dead. At the time of the examination the two overturned trees had a rootage space of between 0.25 and 1.00 m^3. Another examination of trees of the same dimensions in an identical locality shows that the normal rootage space is well over 30 m^3 (Holstener-Jørgensen, 1959a).

This stand was thinned heavily in the winter of 1956/1957. The summer of 1957 was very wet, and a forest guarp told us that during the whole of the summer of 1957 the stand was only accesible for people wearing rubber boots. It is therefore probable that the heavy thinning in connexion with the wet summer has caused a considerable rise of the water-table. Old trees

have a considerable inertia, and this explains why perceptible signs of the calamity were not noticed until 1960. The dry summer of 1959 has presumably contributed to the disclosure of the symptoms.

4. THE POSSIBILITIES FOR DRAINAGE

It is an attractive thought to try to improve the growing conditions for ground-water-sensitive tree-species by artificial drainage. However, it is difficult to drain soils like those described. I want to elucidate this by a single example.

In the spring of 1953 an area was drained at a great depth. The area is level, and the soil is moraine clay with a clay content averaging 20 per cent. at the depth of 50 cm. The area is covered with broadcrowned old oaks with a sparse undergrowth of hazel and hawthorn. In connection with the drainage we laid out a strip of land between two parallel drain pipes. The distance between the drain-pipes is 125 m. In the strip of land ground-water wells were bored at distances of 2.5, 5, 10 m. etc., from the drain-pipes. In these wells the depths of the water-tables were measured every 4 weeks. From the data available I have chosen the measurements from the beginning of 1958. The first measurement is from 17th January, the last

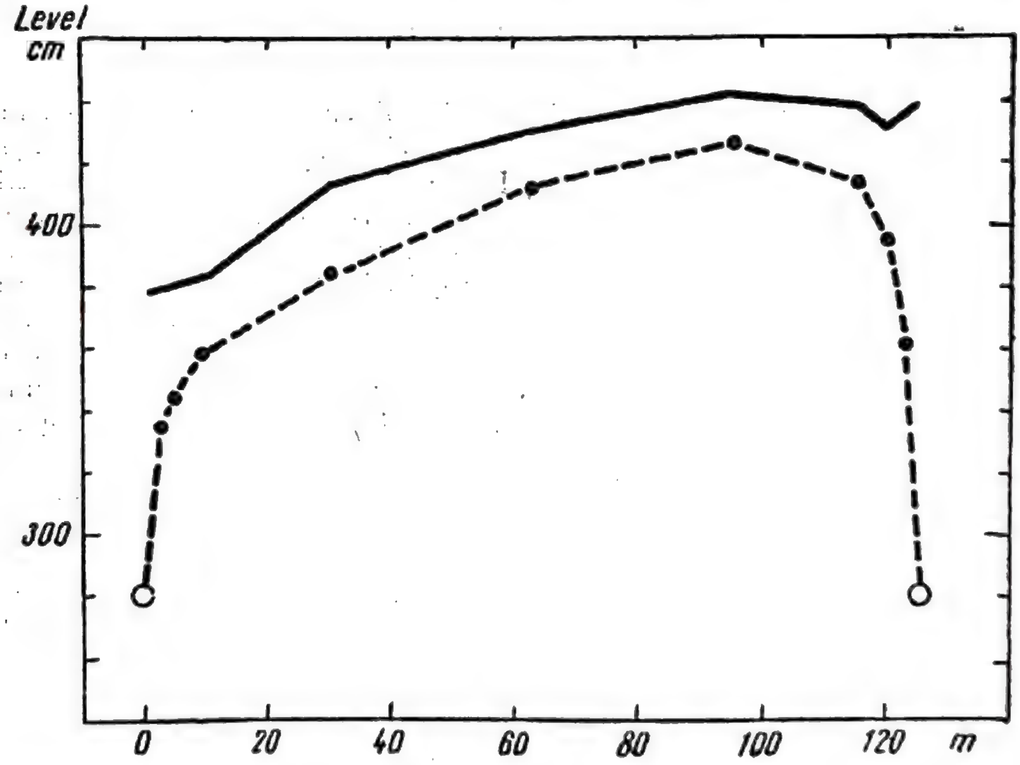

Fig. 7. The average water-table (dashed line) from 17th January through 19th May, 1958, in a drained area. The levels are heights above Danish ordnance datum. The full-drawn line is the soil surface. Left 3" drain-pipe, right 4" drain-pipe.

from 19th May. 5 water-tables are involved. The mean values for these 5 observations have been entered in figure 7 for each particular ground-water well. The figure shows a vertical section of the area. At the left ordinate axis, at the depth of 105 cm, there is a 3″ drain-pipe; at the right ordinate axis, at the depth of 150 cm, there is a 4″ drain-pipe. The dotted connecting line between the computed mean water-tables of neighbouring wells and — at the ends — between the water-table in the nearest well and that in the drain-pipe gives a picture of the average position of the water-table in the area during the experimental period. It seems to appear from the figure that the water-table in the area is only affected by the drainage within a distance of 5—10 m from the drain-pipes.

Observations of this sort may easily lead to the same conclusions as Håkansson (1960) reached after having summed up the results of Swedish agricultural drainage experiments (*l.c.*, p. 284).

In soils with a low permeability it may be more effective to diminish the distance between the ditches than to increase the depths of the ditches, if a certain average lowering of the water-table is aimed at.

Incidentally, at the Danish Forest Experiment Station we have commenced establishing drainage experiments to obtain a further elucidation of these questions.

5. CONCLUSION

I have briefly accounted for the results of some of our investigations of the ground-water-fluctuations in forest on a clayey soil. Such investigations have been made earlier. For example, I may remind you of the classical investigations made by the Russian Ototzki at the turn of the century. His work inspired similar investigations in a number of other countries (see e.g. Ebermayer, 1900; Henry, 1903; Hesselman, 1917; Bühler, 1918). Apparently, all these investigations had the definite aim to compare forest with other types of vegetation (field, meadow, steppe, etc). Ototzki found that forest lowers the water-table deeper than any other type of vegetation. From this he concluded that forest consumes more water than other types of vegetation. His results were confirmed from certain quarters and contested from others. Engler (1919), for instance, has criticized Ototzki's investigations rather severely.

Passing on to recent years, we discover that the discussion has flared up again. In 1959 Grudinskaya and Shpak published new measurements from the Ukraine. Several of their ground-water wells are wells which Ototzki used for his measurements. They conclude that their material "fully substantiate the conclusions of P. V. Ototzki".

Simultaneously Rakhmanov (1959) has criticized a considerable part of the existing literature on the effects of forest on the water-table. Several of Rakhmanov's arguments have earlier been put forward by Engler (1919).

It is not for me to decide whether the disagreement is based entirely on grounds of fact, or it is politically inspired. It is easier to argument for a pro-

gramme of afforestation, if one may claim that afforestation among many other advantages also has the advantage of increasing the reserves of water in the soil.

More references could be put forward, forming a still more complex picture of the problem. However, it is not necessary, for these references are sufficient to demonstrate that here is a rather unbroken field inside the science of soil physics.

That this science has been relatively neglected does not mean, however, that it is uninteresting, and still less that it is without importance. Forestry may gain considerably from an intensified research, especially in places where in periods the water-table is immediately below the surface of the ground. Knowledge of the water-table conditions affects a number of important silvicultural decisions, of which I will mention three:

1) choice of tree-species (ground-water-sensitive/tolerant tree-species);
2) choice of methods of planting (e.g. clear-cutting/shelterwood-cutting);
3) decisions whether or not drainage should be carried out.

The cited literature shows that attempts have been made to make use of measurements of water-tables when estimating the water consumption of various types of vegetation. This shows in itself that people concerned with watershed management have also a considerable interest in ground-water research.

Finally, I want to point out that also types of agriculture, where for instance drainage has been carried through to a great extent, seem to have been working on a rather loose foundation of research results. In Denmark the farmers have had large areas drained in the course of time, and very considerable State aids have been granted in support of this work. The experimental results which motivated the drainage as well as the State aids have been characterized by Aslyng by the following observation (1962, p.130):

"Thus the Danish experiments do not satisfactorily prove the value of drainage, nor do they indicate the most advantageous drainage intensity".

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SUMMARY

The seasonal ground-water fluctuations have been followed in a number of forest-tree stands on clayey soils with a high ground-water table. It is shown that the lowering of the ground-water table during the growing season is a function of the evapotranspiration and the rootage depth of the stand. These quantities are functions of the age of the stand and, besides, differ from tree species to tree species. Thinning reduces the evapotranspiration, the ground-water table is lowered less deeply, and the rootage space is diminished. This may lead to disastrous drowning.

It is demonstrated that draining soils like those investigated is a difficult and therefore an expensive task. Since this is not generally realized, it is pointed out that drainage experiments are needed.

RÉSUMÉ

Dans un nombre de peuplements forestiers, sur sols argileux à plan d'eau phréatique élevé, on a établi les fluctuations saisonnières de la nappe phréatique. On montre que l'abaissement du plan d'eau de la nappe phréatique, pendant la période de croissance, est une fonction de l'évapotranspiration et de la profondeur d'enracinement du peuplement. Ces grandeurs sont des fonctions de l'âge du peuplement et en outre varient d'une essence à l'autre. L'éclaircissage réduit l'évaporation, le plan de l'eau phréatique descend moins et la zone radiculaire diminue. Cela peut conduire à des submersions désastreuses.

On montre qu'il est difficile et donc côuteux de drainer des sols pareils à ceux qui ont été examinés. Du fait que ce problème n'est nullement tiré au clair, on souligne que des essais de drainage s'imposent.

ZUSAMMENFASSUNG

In einer Anzahl von Waldbaumbeständen auf Lehmböden mit hohem Grundwasserstand sind die jahreszeitbedingten Grundwasserschwankungen festgestellt worden. Es wird gezeigt, dass die Senkung während der Wachstumsperiode eine Funktion der Evapotranspiration und der Wurzeltiefe des Bestandes ist. Diese Grössen sind eine Funktion des Bestandesalters und sind im übrigen von Baumart zu Baumart verschieden. Beim Auflichten vermindert sich die Evapotranspiration, der Grundwasserstand senkt sich weniger, und der Wurzelraum wird kleiner. Dies kann zu Ertrinkungskatastrophen führen.

Es wird gezeigt, dass es schwierig und daher kostspielig ist, Böden wie die untersuchten zu entwässern. Da hierüber kaum volle Klarheit besteht, wird die Notwendigkeit von Entwässerungsversuchen hervorgehoben.

DISCUSSION

H. E. STREMME (Deutsche Bundesrepublik). In Schleswig-Holstein haben wir ähnliche Untersuchungen auf gleichartigen Böden unter Acker gemacht und ähnlich starke Grundwasserschwankungen gefunden. Ich möchte einige ergänzende Fragen stellen:

1. Wie nennen Sie die Böden als Bodentyp?
2. In welcher Tiefe finden Sie den Reduktionshorizont?
3. Die Grundwasserschwankungen wurden besprochen. Welche jährliche Extreme treten auf und wie hoch sind die Extreme über mehrere Jahre? In Schleswig-Holstein fanden wir z. T. 150 cm in einem Jahr und 250—300 cm als extreme Schwankungen für mehrere Jahre.

H. HOLSTENER-JØRGENSEN. 1. I call these soils gley-soils and *not* pseudogleys. 2. Reduction horizon is found in a depth of from 2.50 m to 4.50 m. 3. Ground-water fluctuations are very much bigger in dry years than in years with normal climate. The lowest water table in a normal year is found at a depth of 2.50 m, you may find it at a depth of 4.50 m. in a dry year (f.i. 1959).

W. H. VAN DER MOLEN (Netherlands). Which kind of soil was present in the experiments? From the ground-water curves it looks like an impermeable subsoil with very little storage-capacity with a more permeable top soil.

H. HOLSTENER-JØRGENSEN. The top soil was sandy (uppermost 20—40 cm). We know from experience that when the soil is saturated, 1 mm precipitation will cause up to 200 mm water table rise in the deep layers.

B. FOKKENS (Netherlands). Mr. Holstener has to do with a soil profile consisting of an impervious subsoil and a more or less permeable topsoil. Why not using shallow open drains in place of deep tile drains?

H. HOLSTENER-JØRGENSEN. I am concerned with deep tile drainage because practical forestry now is heavily interested in deep-tile drainage. I tried to tell by citing some Swedish conclusions that I believe in shallow ditching as a reliable practice.

K. VAN DER MEER (Netherlands). Dr. Holstener has used tile drainage for his experiments. In Holland some experiences exist on growth of roots of trees in the tile drains and impeding the drainage in this way similar observations occur in Denmark?

H. HOLSTENER-JØRGENSEN. Our experience from some old tile drainage practices in forestry is that roots are not as dangerous in closed tree-stands as f.i. in wedge-rows or in parks with scattered trees. We have f.i. seen that in a 150 years old mixed stand of beech oak and others a drain-tile at 100 cm depth has not been damaged ur til rcw

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PRESERVATION OF SOIL STRUCTURE ON MECHANIZED FARMS IN BELGIUM

L. DE LEENHEER [1]

In the loam region, which is the most important agricultural region of Belgium, a soil structure study was made in 1959, 1960 and 1961, based on field evaluations, to study the practical influence of soil management factors on soil structure. In such a regional study the distinction between a soil compaction index and an index of aggregate deterioration, both evaluated in the field, is very important, because a given soil management factor may influence much more the soil compaction than the structure stability, or vice versa.

The indices used in this study represent a frequency combined with the evaluation of the degree of deterioration. Example: 100 fields or plots are visited and 24 times an evident soil compaction at plow-sole depth is observed, 40 times the soil compaction is less visible and 36 times no compaction is detected. The frequency per cent of the evident compaction (in this case 24) is added to half the value of the frequency per cent of the less visible deterioration (40 : 2 = 20) and the total (44) is called the field index of soil compaction. In the same way the field index of aggregate deterioration is calculated (Vandamme, De Leenheer and De Boodt, 1963).

To detect soil compaction a simple penetrometer is used, and simultaneously the total soil porosity is evaluated in the field; preference is given to an evaluation at field capacity using a soil sample ring 3 inches or 7,62 cm in diameter. The total soil porosity is evaluated at three depths: in the arable layer at about 4 inches depth (10 cm), in the plow-sole and immediately below the plow-sole. The conclusion is made in terms of evident plow-sole, beginning or no visible plow-sole. A similar evaluation of aggregate deterioration is made with three gradations: evident, beginning or not visible. It is based on the observation of the crust formation at the soil surface and on the observation of a vertical wall, about 10 inches deep (the profile of the arable layer and its plow-sole). In the loam region of Belgium attention in paid to detecting yellow-white spots of fine sandy material in the arable layer; they are typical in loam soils with deteriorated aggregate stability; the spots have a diameter of the order of magnitude of the centimeter. The more the spots appear, the more evidence there is for stability deterioration. At the same

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time much care is bestowed on detecting the presence of white-gray spots of calciumcarbonate (chalk, sugar lime, marl, etc.). This is necessary to clasify the arable soils in soils with or without a reserve of visible calciumcarbonate. In the loam soils of Belgium these spots are very small (with a diameter of the order of magnitude of a millimeter), but the presence of such a visible carbonate reserve is now considered as the very first factor (in Belgian loam soils) for a good aggregate stability and seems to be more important than any other crumb stability factor, including organic matter (taking into account also the expenses made by the farmer).

It is evident that the conclusions of a regional soil structure survey are only valid for the region which has been studied: but it is also a fact that the real value of some soil management recommendations can only be proved by field observations, taking into consideration the whole problem of regional mechanized farming (soil type and slope, texture and subsoil influence on permeability, crop rotation, organic and green manure, light or heavy tractor, tc.). The following results of the soil structure survey of the Belgian loam soils are very instructive in this respect. They are based on about one thousand field evaluations of structure.

1. SPECIFIC SOIL STRUCTURAL STATUS IN THE SUBLANDSCAPES OF THE SAME LOAM REGION

Although the Belgium loam region is considered to be an homogeneous region from the standpoint of soil texture, five sublandscapes can be distinguished from the agricultural standpoint.

The differences between the sublandscapes are a consequence of the nature of the geological substratum (chalk, sand or clay), which influences the importance of the meadow-area, and consequently the cattle-density per ha arable land. As an other factor of regional differences the size of the farms must be mentioned; the smaller the farm size, the less important is the use of heavy tractors on the field and the higher in general is the cattle density.

One gets a good idea of the frequency of the small and large farms in an area by the frequency of the (exclusively) horse traction and (exclusively) heavy tractor traction. The difference of this sum with one hundred is the frequency of the mixed traction, the plowing then being normaly done with a light tractor (see § 3. Influence of traction).

As land use, crop rotation and soil management are different in the various sublandscapes of the loam region, the field indices of soil compaction and of stability deterioration are different too. Those two aspects of soil structure deterioration seem to be mutually independent.

Table 1 shows that two different sublandscapes, such as the „dry Hesbaye" and the „Humid Loam Area", may have the same field index of plowsole compaction but a quite different index of stability deterioration, the latter decreasing when the cattle-density (organic manure) increases. A more striking example of the mutual independency of the two soil structure aspects is found in the „Normal Loam Area"; in the Western part, with the highest cattle

density, a field-index of plow-sole compaction is found which is only half the value of the same index in the Eastern part, with the lowest cattle density, although the indices of stability deterioration are nearly the same. It becomes clear that in the Normal Loam Area the difference in soil compaction frequency is related to the type of traction, if one knows that the frequency of heavy tractor traction is only 5 per cent in the Western part, but nearly 50 per cent in the Eastern part of the Normal Loam Area.

Table 1

Influence of the sublandscapes within the loam region

Subland-scape	Nature of geological substratum	Number of field evaluations of structure	Cattle density per Ha arable land	Frequency of only horse traction	Frequency of only tractor traction	Field index of plowsole compaction	Field index of stability deterioration
Normal Loam Area, West	Tertiary fine sand	201	2.9	28	5	22	67
Normal Loam Area, East	Tertiary fine sand	284	1.1	18	48	45	73
Loam Area of Brabant	Tertiary coarse sand	146	1.0	6	60	40	68
Loam Area of Hesbaye	Secondary chalk	153	0.7	5	60	32	59
Humid Loam Area	Tertiary clay	156	2.0	24	31	34	38

2. INFLUENCE OF SLOPE AND SOIL TYPE

To study the influence of the topography on soil structure, large rolling fields have been chosen on which three soil types are developed, composing the normal toposequence of the well drained loam region. In this case the three profiles are: the most frequent loam profile on the plateau, the normal loam soil on the lower part of the slope (partly colluvium), and the typical colluvium profile in the dry depression. As the whole toposequence must be well-drained (drainage class b) for this comparison the Humid Loam Area is not represented in table 2.

There is no doubt that the slope soil is really sensitive to plow-sole compaction, but not so sensitive to stability deterioration. Probably tire slipping and vibration of a light tractor on slopes are important factors of plow-sole compaction. The small variation in soil compaction in the toposequence of Hesbaye may be explained by the general use of heavy tractors on the mechanized farms.

Table 2

Influence of topography on soil structure (loam soils)

Normal soil type (well-drained) on	Normal loam Area ; West		Normal loam Area ; East		Brabant		Hesbaye	
	Pl.s*	St.d**	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d
Plateau	14	74	41	75	36	68	29	51
Slope	28	80	51	75	55	73	33	66
Depression	18	68	40	72	50	75	36	66

* Pl.s — field index of plow sole compaction.
** St.d — field index of stability deterioration.

3. INFLUENCE OF TRACTION

Three kinds of traction are distinguished: exclusively horses, exclusively tractors, or mixed. A mixed traction means that only the plowing is done with a tractor, which is normally a light tractor (less than 2,000 kg weight); the other soil management operations are done by horses. If all operations are done with a tractor, the latter is normally a heavy one (more than 2,000 kg weight). The data given in table 3 prove the influence of the kind of traction.

Table 3

Influence of the kind of traction on soil structure (loam soils)

Kind of traction	Normal loam area-West		Normal loam area-East		Brabant		Hesbaye		Humid loam area	
	Pl.s	St.d	Pl.s	St.d.	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d
Horses	21	58	18	63	28	55	13	25	29	16
Mixed	23	71	14	75	38	71	39	60	34	35
Tractor	15	60	55	75	45	72	30	61	42	52

It is evident that soil structure on farms with only horse traction is always better than on mechanized farms: this is true for soil compaction as well as for aggregate stability. The comparison of the mixed traction with exclusively tractor traction shows in general no real difference as far as aggregate stability is concerned. As far as soil compaction goes the highest compaction index would be expected for tractor traction. However, plow-sole compaction under mixed traction is the highest in 2 landscapes out of 5, and these 2 landscapes represent the extremes in cattle density, which does not facilitate the explanation of the frequency found.

4. INFLUENCE OF THE WEIGHT OF THE TRACTOR

In the Eastern Normal Loam Area special attention has been paid to the influence of the weight of the tractor, taking into account the amount of soil organic matter (both the cattle density and the presence of alfalfa in the crop rotation).

The following data show the excellent structure improving effect of the alfalfa on mechanized farms, where only the use of heavy tractors is made. The structure deteriorating effect of the light tractor on fields with alfalfa in the rotation is more pronounced on aggregate stability than on plow-sole compaction (table 4).

Table 4

Influence of the weight of the tractor on soil structure

Weight of tractor	Fields with alfalfa		Fields without alfalfa in the rotation — cattle density in units per Ha arable land					
			0—0.8		0.9—1.2		⩾1.3	
	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d.	Pl.s	St.d
Light tr.	36	68	81	86	55	84	37	77
Heavy tr.	29	32	52	74	45	68	36	76
Caterpillar	—	—	81	95	—	—	—	—

The data show also that the bad influence of the light tractor on fields without alfalfa in the rotation is especially evident on plow-sole compaction, and that the structure deteriorating influence is decreasing with an increasing amount of soil organic matter. For a cattle density higher than 1.3 the structure deteriorating influence of the light tractor becomes negligible.

The very bad effect of tractor vibration on soil structure (compaction and stability) is made evident by the influence of the caterpillar traction, which is in use on some larger farms with an extreme low cattle density. It is clear that the structure deteriorating influence of the caterpillar has exactly the contrary effect to the one the farmer expected when buying this expensive machinery.

The bad influence of wheel slipping and vibration of the light tractor is also proved by the increase of plow-sole compaction on slopes versus pla-

Table 5

Changes in plow-sole compaction with topography under influence of the kind of traction

Kind of traction	Normal loam area, East		Hesbaye	
	Plateau	Slope	Plateau	Slope
Mixed traction	33	53	29	47
Only tractor	52	66	31	28

teau. The increase in compaction frequency is more important under mixed traction (ordinarily made with a light tractor although horses are also used) than under tractor traction exclusively (which is generally made with a heavy tractor) (table 5).

5. INFLUENCE OF SOIL ORGANIC MATTER

The amount of soil organic matter, which is necessary to maintain a good-soil structure, is very different in the 5 sublandscapes of the loam region of Belgium, and, of course, changes in cattle density and the kind of crop rotation (including green manure or alfalfa). In the Western Normal Loam Area, where the number of small farms (less than 10 ha) is high, the cattle density is high too, which is accompanied by a general practice of producing forage crop as second crop in the same year, such as rapes. Here a value of about 3 units of cattle density per ha arable land seems to be necessary; the average cattle density on the farms with evident stability deterioration of the soils was 2.6; on the farms with only a beginning of stability deterioration the cattle density was 3.5. In the Eastern Normal Loam Area an important difference was found, both in soil compaction and in aggregate stability, at a cattle density higher or lower than a critical value of 1.7. In the Brabant Landscape this critical cattle density is 1.3 and in the Humid Loam Area this value is 2.1. Therefore the amount of soil organic matter which ought to be given to a soil of a known textural class (e.g. the loam soils) cannot be generalised or given in terms of cattle density; the amount changes too much with the kind of soil management and soil use.

The influence of soil organic matter, however, can nicely be illustrated by comparing the soil structure which results if soil organic matter is given only once or if it is given twice or more times during the crop rotation.

As an example of only one application we mention either stable manure or green manure; as an example of more applications we mention the gift of both, or the gift of green manure combined with the gift of the crop residues (straw of cereals and leaves of sugar beets).

Data in table 6 show the improving influence of a double gift of soil organic matter during a rotation.

Table 6

Influence of a single or multiple application of organic matter on soil structure

Application of organic matter per crop rotation	Brabant				Hesbaye			
	cattle density				All soils		Soils in the depression	
	<1,3		≥1,3					
	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d
Once	50	79	45	60	32	69	42	74
Twice or more	39	72	28	64	31	39	23	50

In the Brabant sublandscape the effect on the aggregate stability is not important, but is very high on plow-sole compaction. In the Hesbaye region the improving influence of a double gift of organic matter is important on the aggregate stability of all soils, is only marked on plow-sole compaction in the soils of the depression.

6. INFLUENCE OF A VISIBLE RESERVE OF CARBONATE

This factor seems to be the most important, for the simple reason that its effects are the best visible and most evident on both field indices of soil structure, as can be seen in table 7.

Table 7

Influence of a visible reserve of $CaCO_3$ on soil structure (loam soils)

Reserve of calcium-carbonate	Normal loam area West; all soils		Normal loam area-East				Brabant				Hesbaye			
			cattle density				cattle density				All soils		Soils on slope	
			0.9—1.2		>1.3		<1.3		>1.3					
	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d	Pl.s	St.d
Visible	10	59	38	60	33	71	26	63	37	59	29	41	21	41
Not visible	28	72	60	88	37	80	63	88	35	65	36	82	46	91

Very striking is the improving soil structure effect of carbonate on soils poor in organic matter; if cattle density is higher than 1.3 per ha arable land the improving effect of the reserve of $CaCO_3$ on plow-sole compaction is less marked or even inexistent, but still visible for aggregate stability. In the Hesbaye region, where the average cattle density per Ha arable land is only 0.7, the improving influence of a carbonate reserve in the soil is very striking. Roughly speaking one might say that both practical aspects of soil structure deterioration, i.e. stability deterioration and plow-sole compaction, are twice as high without than with a visible carbonate reserve. In the Normal Loam Region, Western part, where the average cattle density is the highest, 2.89, the improving effect of the carbonate reserve is low for the aggregate stability, but very striking for plow-sole compaction. This is probably related to the fact that in this area the mixed traction (and consequently the traction with a light tractor) has the highest frequency (67 per cent).

The evident improving effect of a reserve of $CaCO_3$ on loam soils has led to an important practical conclusion in Belgium. On mechanized farms, suffering from soil structure deterioration (assuming no $CaCO_3$-reserve is visible, although the pH may be about 7), the application of 50—60 tons/ha of $CaCO_2$ is recommended; in Belgium the most economical form of $CaCO_3$ is sugar lime (lime from sugar factories), because the value of its nitrogen and

phosphorous content covers the cost of the product. After two crop rotations a second application of about 15 tons is recommended.

The soil structure survey described in the previous pages made the study of the influence of other factors also possible, such as plowing at constant or varying depths, plowing before or after winter time, regular use of sodium-rich fertilizers, specific influence of alfalfa in the rotation, the deteriorating effect of a harvest of sugar beets in a rainy autumn, etc. Details about these less important or more regional factors, however, cannot be given here.

SUMMARY

In the loam region of Belgium a soil structure study was made in 1959, 1960 and 1961, based on field evaluations of soil structure, to study the practical influence of soil management factors on soil structure. In such a regional study the distinction between a soil compaction index and an index of aggregate stability deterioration, both evaluated in the field, is very important. Both indexes represent a frequency combined with the evaluation of the degree of deterioration. The field indexes of soil compaction and of stability deterioration are mutually independent.

The study of the soil types of a well-drained toposequence proved that the slope soil is the most sensitive to plow-sole compaction, but not so sensitive to stability deterioration. Tire slipping and vibration of a light tractor on slopes are important factors of plow-sole compaction.

The bad influence of the light tractor (less than 2,000 kg weight) is evident, especially on plow-sole compaction, and the structure deteriorating influence is decreasing with an increasing amount of soil organic matter. The very bad effect of tractor vibration on soil structure was made evident by the influence of the caterpillar traction.

The influence of a visible reserve of carbonate seems to be the most important. Very striking is the improving effect of carbonate on soils poor in organic matter.

RÉSUMÉ

Dans la région limoneuse de la Belgique, une enquête a été faite en 1959, 1960 et 1961, basée sur des évaluations de la structure du sol au champ. Le but était l'étude de l'influence pratique sur la structure des différents facteurs de l'entretien du sol. Dans une étude régionale pareille, il importe de distinguer un indice de compaction du sol et un indice de la détérioration de la stabilité des agrégats. Chacun des indices représente une fréquence combinée avec l'évaluation du degré de la détérioration. Les indices d'évaluation de la compaction de la semelle de labour et de la dégradation de la stabilité sont mutuellement indépendants.

L'étude des types de sol d'une toposéquence normale bien drainée montre que le sol de pente est le plus sensible à la compaction de la semelle de labour, mais qu'il est moins sensible à la dégradation de la stabilité des grumeaux. Ce sont probablement le dérapage et la vibration du tracteur léger sur la pente qui constituent les facteurs importants de la compaction de la semelle de labour.

L'influence défavorable du tracteur léger (poids inférieur à 2 000 kg) est indéniable, spécialement sur la compaction de la semelle de labour; l'influence dégradante sur la structure devient plus faible avec une teneur croissante en matière organique. L'influence très mauvaise de la vibration du tracteur sur la structure du sol a été prouvée par l'emploi d'une traction à chenilles (caterpillar).

La plus importante semble être l'influence d'une réserve visible de carbonate. L'amélioration due au carbonate est très manifeste dans les sols pauvres en matières organiques.

ZUSAMMENFASSUNG

In der Lehmgegend von Belgien wurde in 1959, 1960 und 1961, eine Bodenstrukturuntersuchung mittels Feldschätzungen unternommen mit dem Ziel den praktischen Wert der verschiedenen Bodeninstandhaltungsmassnahmen festzulegen. In dieser regionalen Untersuchung wurde der wichtige Unterschied zwischen einem Bodenverdichtungsindex und einem Aggregatzerstörungsindex berücksichtigt. Beide Indexe wurden im Felde geschätzt und sind unabhängig voneinander. Jeder geschätzte Index ist das Ergebnis einer Frequenz kombiniert mit dem geschätzten Grad der Strukturzerstörung.

Der Einfluss von Bodentyp und Topographie wurde in einer gut dränierten Toposequenz untersucht. Der Hangboden ist gegenüber Pflugsohlenverdichtung der meist empfindliche der Sequenz, aber er ist weniger empfindlich gegenüber Stabilitätsdegradation. Wahrscheinlich ist das Rutschen der Kautschukreifen und die Vibration des leichten Schleppers auf den Hängen ein wichtiger Faktor der Pflugsohlenverdichtung.

Der ungünstige Einfluss des leichten Schleppers (unter 2 000 kg Gewicht) ist offensichtlich, besonders auf die Pflugsohlenverdichtung; der Degradationseinfluss nimmt aber mit zunehmenden Mengen an organischem Material ab. Der sehr ungünstige Einfluss der Vibration des Schleppers auf Verdichtung und Stabilität wurde durch die Einflüsse des Raupenkettentraktors (Caterpillar) augenscheinlich gemacht.

Der Einfluss einer sichtbaren Karbonatreserve scheint für mechanisierte Betriebe der wichtigste zu sein. Sehr deutlich ist der Strukturverbesserungseinfluss der Karbonatreserve auf Böden, die an organischem Material arm sind.

DISCUSSION

D. HILLEL (Israel). The results showing that light tractors cause greater damage than heavy tractors, and that crawler tractors are more damaging to soil structure than wheel-type tractors are surprising. Can you suggest an explanation? How were the measurements taken: in the track, between the trails or at random?

Was a controlled experiment conducted to check the results of the survey?

L. DE LEENHEER. The damage caused to soil structure by light tractors and caterpillars is very evident on slopes. Wheel slipping and vibration (and in the case of caterpillars the heavy vibration only) are responsible for the deterioration. About 1,000 field observations were made at random. This regional investigation was preceeded by the study of several experimental fields started in 1958; a total of about 48 ha of experimental fields for soil structure and physical fertility are now under investigation.

J. M. GOSNELL (South Africa). 1. Were there many kinds of tractors in each group for the study comparing different weights of tractors?

2. Were the field observations of compaction related to penetrometer measurements?

L. DE LEENHEER. 1. There were different kinds of tractors in each group; the type however was not put on our punch-cards; the weight of 2,000 kg was the only criterion to distinguish light and heavy tractor.

2. Yes.

D. KIRKHAM (U.S.A.). Were yield measurements taken to see whether they correlated with the compaction index or structure index or were these correlations inferred from other work? Our work at Ames, Iowa, U.S.A., shows, that for a silty clay loam, compaction to a bulk density of 1.4 g/cc or higher markedly reduces yields.

L. DE LEENHEER. On previous experiments (made on experimental fields) we studied the correlation of yield measurements with structure indices (Results published in the Proceedings of Soil Structure Symposium of Ghent, Belgium, 1958). On an experimental field laid out in 1960—1961 plow-sole compaction was obtained by winter-plowing under rainy circumstances and the yield was markedly reduced. This paper, however, deals with a regional large-scale investigation (1,000 structure evaluations) and the informations given by the farmer about the soil management and soil use were put on punch-cards together with our own field evaluations of structure.

J. DUNGLAS (France). Le cisaillement sous les roues motrices du tracteur, dû au glissement (surtout dans les pentes) n-a-t-il pas une importance essentielle dans l'effet de compactage observé avec les tracteurs légers?

L. DE LEENHEER. Pour les tracteurs légers le glissement des roues motrices a certainement une grande influence, surtout sur les pentes. Cette influence sur la semelle de labour est accentuée par les vibrations fortes lorsque le tracteur léger doit remonter la pente.

L. D. BAVER (U.S.A.). 1. I would like to support Prof. de Leenheer's comments on the effect of the caterpillar tractor on soil compaction. We have in Hawaii caterpillar tractors of various sizes and the amount of compactions is related to the size of the tractor as it increases the ground pressure per square inch.

2. We also are of the opinion that the vibration of tractors has a compacting effect but not as great as weight.

3. We have found the presence of "disc-harrow" soles as well as plow soles. It only takes a very thin layer of compaction to reduce water infiltration and root penetration.

4. We have found that the major impact of compaction on soil structure is the reduction of the aeration porosity.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I+VI. 15

THE INFLUENCE OF SOIL PROPERTIES ON SUITABILITY FOR GRAZING AND OF GRAZING ON SOIL PROPERTIES

G. P. WIND, C. J. SCHOTHORST [1]

Trampling of grassland is a problem growing more and more urgent in grassland farming. This is partly caused by the modern economic structure of agriculture. Labour is rather scarce and expensive. A considerable amount of extra labour is needed if the pastures are trampled because the cattle has to be stalled to avoid large damage. The high stocking rates require a high bearing capacity of the pasture, which is becoming softer by the high amounts of nitrogen fertilizer.

This article deals with the soil physical causes of trampling and the influence of drainage depth. It also gives some consequences of possible improvement methods. The research has been mainly limited to sand-and peat moor pastures.

THE PRESSURE OF THE GRAZING CATTLE

The weight of a cow is about 600 kg, the total hoof area is according to Stegenga (personal communication) about 300 cm^2. The pressure a standing cow exerts on the soil is therefore 2 kg/cm^2. When only two hoofs touch the soil the pressure is 4 kg/cm^2. Young and small cows have a somewhat smaller pressure, about 3 kg/cm^2. These data of Stegenga for Frisian cattle agree with those of Sears (1956) who found 3.3 kg/cm^2 for Jersey cows.

For comparison we mention the pressure of agricultural tractors which is 1 kg/cm^2 at the most. Other tools have no higher pressure, only loaded carriages approximate the pressure of cattle hoofs.

Schothorst (1963 a) measured the bearing capacity with a penetrometer. He found that grassland was badly trampled if the bearing capacity was less than 5 kg/cm^2. Between 5 and 7 kg/cm^2 there was lesser damage.

Only with bearing capacities of 7 kg/cm^2 and more, the pastures appeared to be sufficiently firm. The real hoof pressure seems therefore to be some-

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what greater than the quotient of weight and hoof area. This is rather obvious as the hoofs are not being placed fully level, and a certain velocity must be accounted for.

SOIL PROPERTIES DETERMINING BEARING CAPACITY

It is clear that organic matter content is important with regard to bearing capacity. Trampling occurs very seldom on sandy soils whereas it is more a rule than an exception on peat soils. Schothorst (1963b) found that net pasture yields of peat-moor and very humous sandy soils were 15 per cent lower than those of solid sandy soils. Pieters (1961) and Schothorst (1963a) observed that susceptibility to trampling increases with organic matter content.

It is also evident that the moisture content is very important. In dry periods no trampling occurs. In wet seasons all clay- and peat-moor pastures are susceptible to trampling. Figure 1 shows the relation between moisture content and the bearing capacity (field data) of some peat-moor pastures with more than 40 per cent organic matter. For moisture contents greater than 65 per cent by volume the bearing capacity is too low and trampling occurs.

The combined influences of moisture and organic matter are shown in figure 2, taken from Schothorst (1963a). The figure contains points, indicating sufficiently firm conditions, and crosses, representing situations with a big trampling risk. Between points and crosses a dividing line is drawn, which we call the trampling boundary line. The higher the organic matter percentage, the higher the trampling boundary lies. The moisture tension of the trampling boundary reaches from about 150 cm for peat soils with more than 50 per cent organic matter via 100 cm for humous sandy soils (15 per cent o.m.) to zero for sand without organic matter.

THE DRAINAGE DEPTH OF PASTURES

In periods in which rainfall is greater than evaporation, the moisture content of the top soil equals field capacity or is even greater. Field capacity means a moisture tension of about 150 cm if the groundwater table is rather deep. In most humous or peaty soils there is a groundwater table at considerably less depth. In those cases, the moisture tension of field capacity equals the depth of the groundwater table in cm. According to the above mentioned moisture tensions of the „trampling boundary", the drainage depth has to be 100 to 150 cm for humous- and peat soils. With smaller drainage depths trampling damage must occur in wet periods according to this theory.

The existing drainage depths of pastures on peat and humous soils are kept considerably smaller, because of the danger of shrinkage and irreversible drying. In Germany Baden (1963) advocates a very deep drainage of peat-moor pastures. It appeared that these soils with a drainage depth of

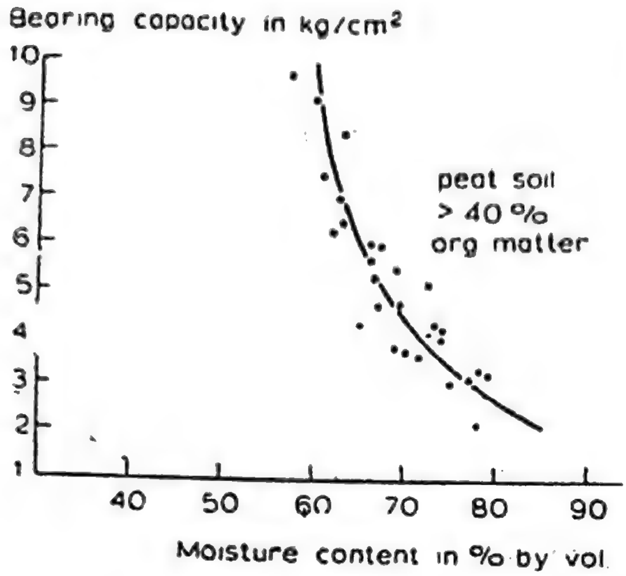

Fig. 1. Relation between bearing capacity and moisture content for peat soils, determined in the field.

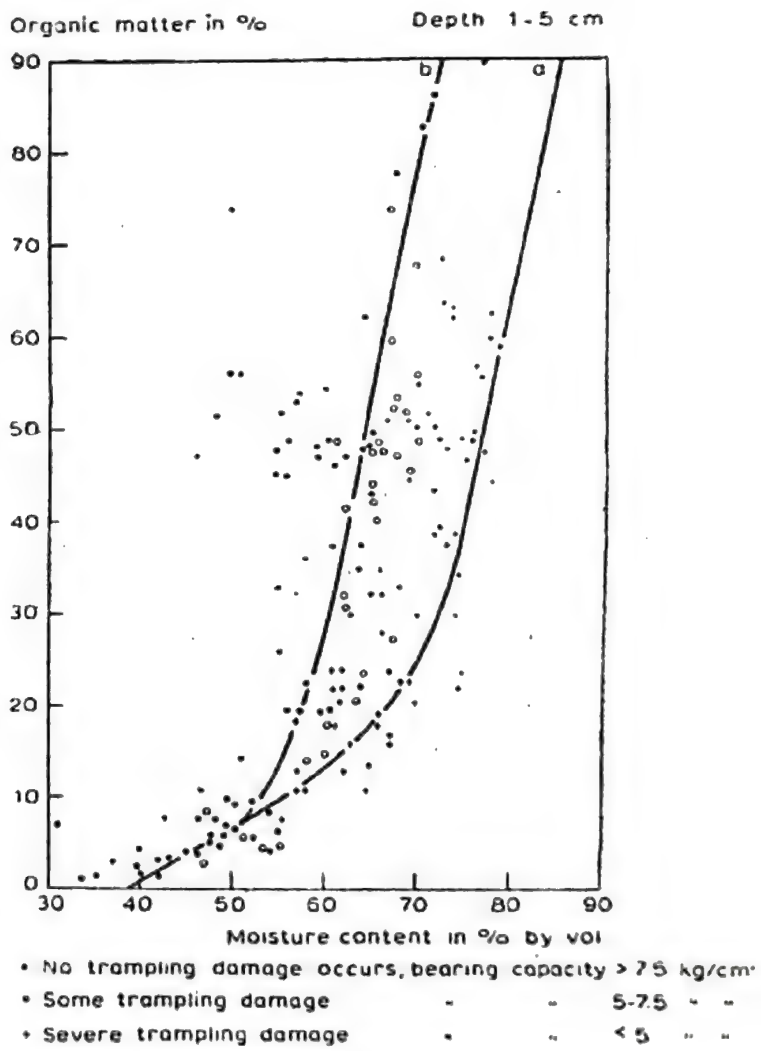

Fig. 2. Susceptibility for trampling as influenced by moisture- and organic matter content in the layer of 1—5 cm below surface of pastures.

1.50 m indeed have a good bearing capacity during wet periods. So it was proved that the bearing capacity is sufficient if the soil is drained to the depths mentioned.

Contrary to the expectation we found two pastures with a sufficient bearing capacity in wet periods with a drainage depth of about 70 cm. Even if the groundwater table did rise higher, the bearing capacity never decreased below 5 kg/cm². Nevertheless those soils were no exception to figure 2, which means that the moisture content of these soils was lower than that of comparable soils.

First we thought of irreversible drying (Wind, 1963) later it appeared that the high bearing capacity was caused by a higher bulk density.

BULK DENSITY AND BEARING CAPACITY

The two exceptional pastures we found had a pore volume in the upper layer of 0.76, while a pore volume of 0.79—0.84 is normal for comparable soils with the same organic matter content of about 40 per cent but a shallower drainage. The differences are rather small, buth the possible variation in pore volume is small too, about 10 per cent for pasture soils with the same organic matter content.

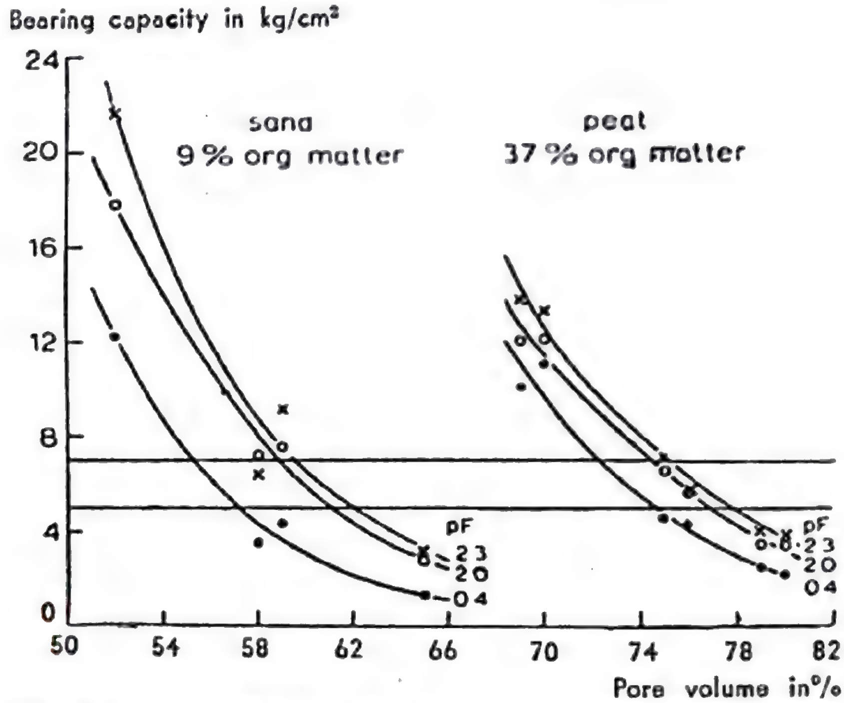

Fig. 3. Bearing capacity of two soils in relation to pore volume according to laboratory readings.

To find the relation between bearing capacity and pore volume a laboratory experiment was made, because in the field there is insufficient variation in pore volume and one can not standardize the organic matter and moisture conditions.

From 8 soils with organic matter contents between 0 and 92 per cent, six artificial samples were made which varied in density between very loose and very dense. Of every sample, in Kopecki-rings of 100 cm^3, the moisture characteristic was determined between 2.5 and 200 cm moisture tension. With moisture tensions of 2.5; 100 and 200 cm (that is pF 0.4; 2.0 and 2.3) the bearing capacity was measured with a probe of 1 cm^2.

Figure 3 gives the relations found between bearing capacity, density and moisture tension for one sand- and one peat soil. It appears that a very dense soil has sufficient bearing capacity in wet as well as in dry conditions. A very loose soil always has a too small bearing capacity. Similar results were obtained for all 8 soils.

So pastures on soils of high bulk density will not be trampled. The laboratory experiment did prove that the high bearing capacity of the two pastures mentioned was indeed caused by a high bulk density. Now the question arises how such a high density has come into being.

COMPACTION BY GRAZING CATTLE

Very loose structures, as used in the laboratory experiment, do not occur in the field, at least not in the upper layer of grassland. Under the pressure of cow hoofs the soil is compacted. Rothamsted Experimental Station made a bibliography (Anonymous, 1963) of literature on this subject. Most of the papers deal with considerable compactions caused by treading and its detrimental effects upon grass growth. Very few data are available about the trampling damage done to the sod.

O'Connor (1956) and Gradwell (1956) observed that the highest compaction did not occur under the wettest circumstances. In literature on soil mechanics one finds that under pressures of short duration compaction is only possible up to the moment complete saturation with water is reached (see Söhne, 1955). For further compaction moisture must leave the soil, which will take longer than the duration of one step of a cow.

By treading on loose sod, the soil is compacted. The bulk density increases and consequently the bearing capacity (fig.3) until this equals the exercised pressure. In dry conditions sufficient bearing capacity can already be reached after a small compaction. The bulk density is then not yet high enough for a good bearing capacity for a subsequent grazing under wetter conditions. So further compaction will occur until a bearing capacity of about 5 kg/cm^2 has been reached also under wet conditions. But it can happen that the soil is already completely saturated with water before sufficient bearing capacity is reached. Since the bearing capacity cannot increase any more, the soil below the hoofs is pushed away, holes appear and the sod will be badly damaged.

The deformation and displacement of the soil is a kind of puddling, which leads to unstable structures and loose soil. So after having been trampled once, the soil becomes more susceptible to new trampling damage.

BEARING CAPACITY AND DEPTH OF GROUNDWATER

In the foregoing part it was shown that the bearing capacity of a soil is determined by its bulk density and its moisture content. The moisture content also determines the degree of compaction which is possible. It is evident that the moisture content is not independent of the bulk density. So bearing capacity, moisture content and bulk density are heavily interrelated. In such a feed-back system a very stable equilibrium generally exists.

In order to obtain a better insight in this complex, a quantitative approximation is needed. If 100 ml of soil is compacted from 80 to 75 per cent pore volume, 20 ml of solid parts had in the beginning 20 per cent of total volume; after compaction it is 25 per cent. So the total volume decreased by compaction from 100 to 80 ml. If the moisture content originaly was 50 per cent, that is 50 ml, it becomes $\frac{50}{80} = 62.5$ per cent by volume after compaction. After continued compaction to 71.4% pore volume, the moisture also becomes 71.4 per cent. Then complete saturation has been reached, beyond which further compaction is not possible.

In figure 4 the process of compaction is graphically presented for a peat moor soil with 37 per cent organic matter. The ascending full lines represent the relation between pore volume and moisture content for a constant amount of moisture. These lines, called the compaction lines, end in a descending full line, which represents complete saturation. At the saturation line the moisture tension is indicated which was present if the soil had a pore volume of 80 per cent before compaction

The compaction lines are not parallel. They cross in the theoretical center of the co-ordinate system, where the pore volume is 100 per cent and the moisture content is zero. There the volume of the soil is infinitely great and, as the amount of moisture is finite, moisture content is zero.

It is striking that the possibility for compaction is rather limited *A* soil with 80 per cent pores and 50 per cent moisture, so with an air content of 30 per cent can only be compacted to 71 per cent pores, so over 9 volume per cent. The same is to be seen at the top of the figure. The soil with 50 per cent air can only be compacted over 1 per cent of its volume.

As the bearing capacity is determined by bulk density and moisture content, for every place in figure 4 a value for the bearing capacity can be given. One can find these values in figure 3. They need conversion from pF or moisture tension to moisture content with the aid of figure 5. In figure 3 it can be seen that with a pore volume of 77 per cent and a pF 2.0 (moisture tension 100 cm), a bearing capacity exists of 5 kg/cm². In figure 5 one reads on the pF-curve for a pore volume of 77 per cent that a pF 2.0 corresponds with a moisture content of 63 per cent.

So one can write a value of 5 for the bearing capacity in figure 4 at the point where the pore volume is 77 per cent and the moisture content is 63 per cent. In this manner all the bearing capacity values were placed in figure 4. Through those values broken lines were drawn for equal bearing capacity. Figure 4 can now be used to determine which bulk density will come

into being as a result of a certain pressure. If a soil with 80 per cent pores and 50 per cent moisture is compacted by a pressure of 5 kg/cm², a pore volume will be reached that is determined by the point where the compaction line which runs through (80 ; 50) crosses the bearing capacity line of 5 kg/cm². This

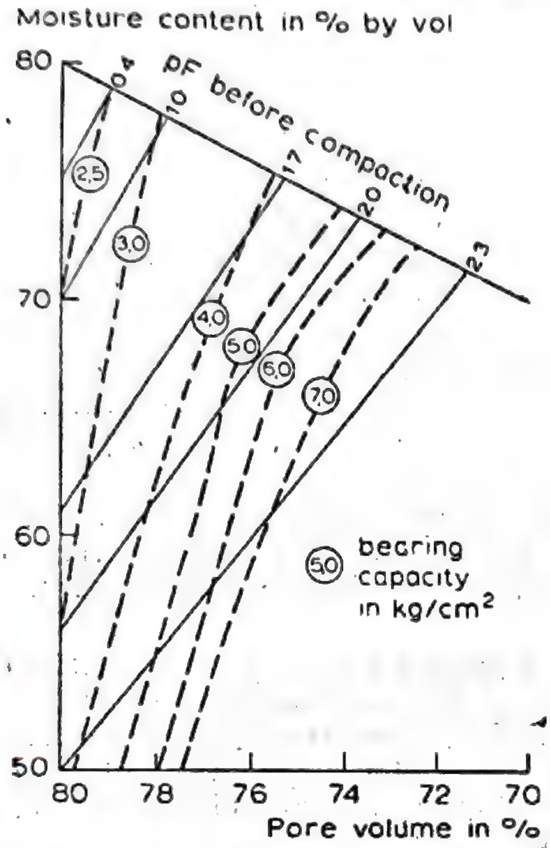

Fig. 4. Relation between moisture content and pore volume for soils under compaction (solid lines) and corresponding bearing capacities (broken lines).

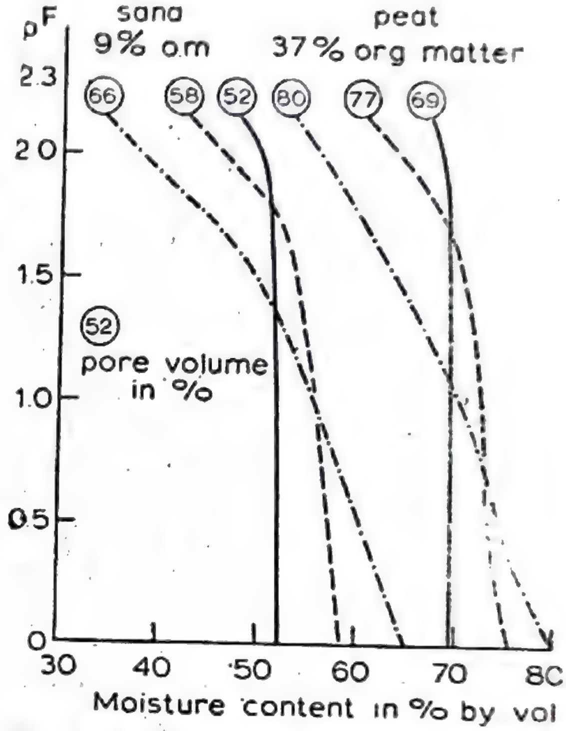

Fig. 5. Moisture characteristics of two soils, as influenced by their density.

gives 78 per cent pore volume. Had we begun with 56 per cent moisture, than compaction would go to 76.5 per cent pore volume. If there originally was 61 per cent moisture or still more, the soil could not be compacted to a bearing capacity of 5 kg/cm². The line of 5 kg/cm² bearing capacity does not cross the compaction line which runs through (80 ; 61). In that situation trampling damage will occur.

The maximum compaction occurs if this soil is grazed (hoof pressure 5 kg/cm²) at a moisture tension of 70 cm, that is pF 1.8 to 1.9. In that case the pore volume decreases to 74 per cent where the soil density is that large that even at complete saturation a sufficient bearing capacity exists. Of course this does not last forever because biological activities, and frost and thawing loosen the soil again. But pastures on this peat soil with 37 per cent organic matter, will be continuously firm if they are regularly grazed at a moisture tension of about 70 cm. Those tensions occur often in wet periods in cases where the depth of the groundwater table is about 70 cm.

In this way it was proved that a sufficient bearing capacity of the two particular peat pastures we found, can be reached at medium drainage depths of about 70 cm. The normal drainage depth in such areas is 30 cm. Deeper drainage makes greater compaction possible, which gives a higher bulk density and with that a higher bearing capacity.

CONCLUSIONS

Peat-moor and peaty pastures have in wet periods only a sufficient bearing capacity for grazing if their bulk density is rather high. The compaction that is required can be caused by grazing cattle if drainage is kept at a sufficient depth.

The low pore volume, corresponding with a high bearing capacity, is not very suitable for good grass growth due to a lack of aeration. All soils from the laboratory experiment had an air content of less than 5 per cent when the soil had sufficient bearing capacity (fig.5).

Although the compaction is confined to the upper 5 cm, all gas diffusion will have to pass that layer. There is reason to assume that the shallow rooting depth of permanent pastures is caused by the insufficient aeration caused by the compacted upper layer.

The conditions for grass growth and grazing cannot both be optimal. In cases where the bearing capacity is always sufficient, the aeration is limited ; where grass growth conditions are optimal, grazing is not possible without disturbing those conditions. In spite of this controversy a rational stockbreeding is possible upon this planet, due to its physical and biological conditions.

All other factors remaining equal, a higher gravitation or higher weight of the animals would inhibit grazing before the growth of plants would be impossible by the compaction effects. It would be interesting to calculate which degree of compaction was caused by such huge animals as the Brontosaurus, with a weight up to 40,000 kg and a soil pressure of about 2 kg/cm^2. Perhaps it would be possible to estimate the amount of plant production upon thus compacted soil and compare this with the amount of food, needed by those reptiles.

In the more familiar case of growing grass and breeding cows, we can try to increase the equilibrium level between aeration and bearing capacity by artificial means. One of these is often used in the Netherlands. Peat soils are covered with a thin layer (about 7 cm) of coarse sand, which contains a high amount of air space even if a very high bearing capacity exists. The peat beneath that layer is hardly compacted, so that there a high pore volume also remains present.

Another artificial means could be the increasing the hoof surface of cattle. By doubling this, the soil would be less compacted, particularly in the top layer. Plastic shoes can be made sufficiently cheap and strong.

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SUMMARY

The bearing capacity depends mainly on the bulk density of the soil surface layer. During grazing, the bulk density increases by compaction until the bearing capacity equals the hoof pressure of the cattle. In wet conditions most soils cannot be compacted to such a degree that a sufficient bearing capacity is reached, because compaction is not possible when the soil is saturated. In that case trampling occurs, which causes damage to the sod.

Theoretically and practically it appears that the depth of the ground-water table in peat and peaty soils must be at least 60 cm below the surface during grazing in wet periods to avoid trampling damage. Where sufficient bearing capacity exists, the air content of the soil is very low, which means that aeration and bearing capacity are controversial properties.

RÉSUMÉ

La capacité portante dépend en principe du poids volumétrique de la couche de surface du sol. Pendant le pâturage, le poids volumétrique augmente par compaction jusqu'au moment où la capacité portante devient égale à la pression des sabots du bétail. Dans des conditions d'humidité, la plupart des sols ne peuvent pas être compactés à un degré tel qu'une capacité portante puisse être atteinte parce que la compaction n'est pas possible lorsque le sol est saturé. Dans ce cas le piétinement se produit, attirant l'endommagement du gazon.

Théoriquement et pratiquement il apparaît que la profondeur du plan d'eau de la nappe phréatique dans les tourbes et les terres tourbeuses doit se trouver au moins à 60 cm. au-dessous de la surface durant le pâturage pendant les périodes humides pour éviter les dégâts provoqués par le piétinement. Là où il y a une capacité portante suffisante, la teneur en air du sol est très réduite ce qui signifie que l'aération et la capacité portante sont des propriétés contradictoires.

ZUSAMMENFASSUNG

Die Tragkraft hängt hauptsächlich vom Raumgewicht der Oberschicht des Bodens ab. Während der Beweidung steigt das Raumgewicht durch Setzung bis die Tragkraft mit der Hufendruckkraft des Viehs gleich wird. Unter feuchten Verhältnissen können die meisten Böden nicht in solchem Grade verdichtet werden, dass eine genügende Tragkraft erreicht wird, weil bei gesättigtem Boden die Setzung nicht möglich ist. In solchen Fällen tritt Verstampfung ein, die der Grasnarbe Schaden zufügt.

Theoretisch und praktisch hat es sich erwiesen, dass der Grundwasserspiegel in Torfen und torfigen Böden wenigstens 60 cm tief unter der Oberfläche während der Beweidung in feuchten Perioden liegen muss, um Verstampfungsschäden zu vermeiden. Dort wo eine genügende Tragkraft vorhanden ist, ist der Luftgehalt des Bodens sehr gering, was bedeutet, dass die Durchlüftung und die Tragkraft gegensätzliche Eigenschaften sind.

DISCUSSION

B. FOKKENS (Netherlands). A fundamental point in Mr. Wind calculations, is that soil compaction is only possible until saturation point. This is true in relatively dry soils, but is it also true in rather wet peat soils?

G. P. WIND. Many investigators, among them Söhne in Germany, found that in a short time only compaction occurs, and no consolidation. The time needed for consolidation is of course dependent on the permeability and the pressure gradient. Very loose, and thus permeable, soils can be consolidated much faster than meadow top soils with a rather high bulk density.

D. HILLEL (Israel). I wish to comment on terminology: *compaction* refers to the expulsion of air from the soil under pressure. Beyond saturation, further densification of the soil should be termed *consolidation*.

G. P. WIND. I agree with that.

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MEASUREMENTS OF STRUCTURE STABILITY OF PASTURE SOILS

W. BURKE, J. GALVIN, L. GALVIN[1]

INTRODUCTION

Several definitions of soil structure have been suggested and the one accepted in this paper is that of Bradfield (1950). He defines soil structure as „the arrangement of the solid particles in the soil profile". Most measurements of soil structure take two factors into account:

1) the relative proportions of solids, water and air, and their arrangement in the soil mass;

2) structure Stability or the degree of resistance to change in the arrangement of the particles.

Methods to measure the relative proportions of solids, water and air are fairly well standardised and reliable and can be used to place a soil arbitrarily into good or bad structural classes. Measurements of structure stability are, however, not so easy and Quinn (1958, 1959) has shown that a wet sieving technique gave misleading results when applied to a number of Irish soils. Wet sieving methods are based on the possibility of aggregate breakdown under the influence of falling rain, coupled with a relatively strong flow of water through or over the soil and are therefore suited to the determination of structure stability of the surface of tilled or bare soils. As most of the soils examined by Quinn were under pasture and had complete protection against the impact of raindrops it was not surprising that the wet sieving technique failed.

SOIL CONDITIONS

About 70 per cent of the total area of Agricultural land in Ireland is under pasture. Reading damage (poaching or pugging) is extensive on these pastures due mainly to the action of the grazing animals' hooves. The stresses imposed on the soil structure by the animals bears no relationship to those provided by the wet sieving method so that a new technique of measuring structure stability under grazing conditions was needed. The ability of a soil to resist treading damage depends primarily on its inherent strength and the weaker

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the soil the more liable it is to damage. It was therefore considered that the results of undrained shear strength tests on soils should give a measure of their ability to resist treading damage.

The moisture content of soil is fundamental to its strength and therefore to the stability of its structure. Many Irish pasture soils are plastic and liable to deformation or structure alteration at moisture contents equal to or greater than their plastic limits (Atterberg). Because of frequent rainfall these soils are often at field capacity for long periods and a soil whose moisture content at field capacity is greater than its plastic limit is unstable under conditions of frequent rainfall. The provision of adequate drainage will help in getting a soil to its field capacity quickly but further drying to a value less than the plastic limit (if this is less than field capacity) is solely dependent on evapotranspiration. The above factors emphasize that the stresses necessary to cause structural changes in any soil depend on the prevailing moisture content of the soil which in turn varies with the climatic conditions.

EXPERIMENTAL

To test the validity of these assumptions six soils, that were known to be subject to treading damage, were selected from widely separated areas of the country and the following measurements made:

1) moisture contents at saturation and in the region of field capacity defined as pF = 2. The determinations were made using suction plate and pressure plate apparatus;

2) the plastic and liquid limits (Atterberg);

3) the undrained shear strength at saturation and at pF = 2 — method as described by Bishop and Hankel (1957).

RESULTS

Mechanical analysis of the soils is given in table 1.

Data on moisture energy relationships and the liquid and plastic limits of the soils are presented in table 2.

DISCUSSION AND CONCLUSIONS

It is evident from table 2 that the moisture retaining capacity of the soils is high. The exceptionally high moisture contents of soils Nos. 4 and 5 is due to the peaty nature of the surface. As all moisture held between the field capacity and plastic limit must be removed by evapotranspiration, it follows that these soils are frequently in an unstable condition — and the greater the gap between field capacity and plastic limit the longer the period of instability. On this basis it can be predicted that Soil No. 6 is more subject to treading damage than soil No. 1. The severity of the damage that occurs

Table 1

Mechanical analysis

Soil No.	Sample depth (ins.)	Percentage by weight					
		Particle size 20—2.0 mm	Coarse sand 2.0—0.2 mm	Fine Sand 0.2—0.02 mm	Silt 0.02—0.02 mm	Clay <0.002 mm	Loss on pretreatment percent
1	3	10.3	9.9	28.7	27.6	23.5	2.4
Oldtown	7	10.0	13.0	26.4	27.2	23.4	1.7
2	3	3.5	11.4	26.9	44.2	14.0	7.0
Herbertstown	7	9.5	11.8	22.7	23.8	32.0	3.0
3	3	9.8	8.7	15.3	57.1	9.1	5.1
Ballinamore	7	20.3	10.5	13.6	23.8	31.8	1.0
4	3	1.2	11.0	40.9	31.9	15.0	6.3
Donegal	7	4.0	18.8	37.9	24.5	14.8	3.4
5	3	0.7	5.3	33.6	46.1	14.3	6.8
Ardagh	7	0	0.4	26.5	39.7	33.4	2.1
6	3	0.8	11.5	30.2	30.4	27.1	3.2
Macamore	7	0.4	11.6	21.0	29.5	37.5	1.3

Table 2

Plastic and liquid limits and moisture percentage by weight

Soil No.	Sample depth (ins).	pF				Plastic limit	Liquid limit
		Saturation	2.0 (0.1 at.)	2.5 (0.33 at.)	3.0 (1.0 at)		
1	3	50	38	36	34	35	44
Oldtown	7	42	29	28	27	28	44
2	3	80	65	61	53	44	70
Herbertstown	7	36	32	30	24	28	49
3	3	82	72	65	57	47	71
Ballinamore	7	45	38	35	33	28	55
4	3	113	97	89	84	54	69
Donegal	7	65	57	52	48	43	60
5	3	182	147	131	119	N.P.*	—
Ardagh	7	52	45	40	39	29	48
6	3	59	47	46	45	30	55
Macamore	7	40	36	32	30	23	50

* *N. P.* — Non plastic.

while the moisture content of the soil lies within the critical range depends on the soil strength under these moisture conditions. The relationship between moisture tension (at saturation and pF = 2) and undrained shear strength is shown in figure 1.

Assuming that undrained shear strength is a measure of structure stability under grazing conditions, the soils can be graded for structure stability on the basis of the data in figure 1, — those soils showing the highest shear values being most stable.

Boekel (1958) has recognized the importance of field capacity and plastic limit measurements and has suggested a structure stability assessment based on the ratio $\frac{\text{Plastic Limit}}{\text{Field Capacity}}$. In table 3 the structure stabilities of the soils are compared both by means of the undrained shear strength at pF = 2 and by Boekel's ratio.

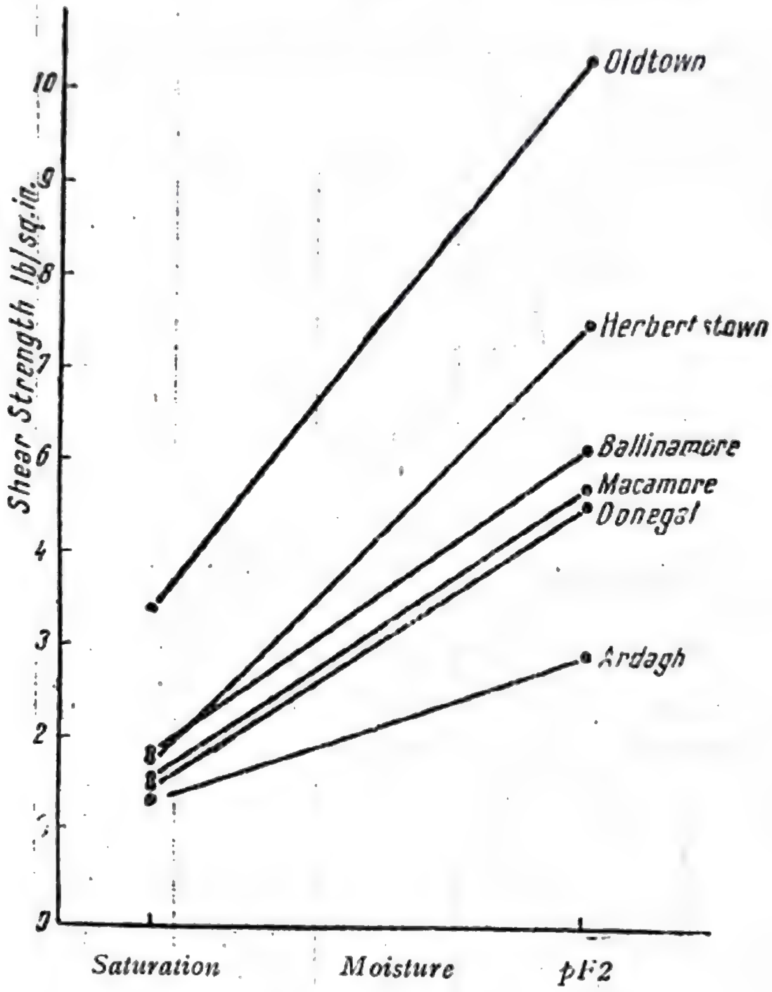

Fig. 1. Undrained shear strength of the soils at saturation and at pF=2.

From the data in table 3 it is seen that both methods of grading place the soils in the same order of structural stability. There is a greater spread in the values obtained by the shear strength method which suggests that it may be a more sensitive test than the $\frac{P.L.}{F.C.}$ ratio. The undrained shear strength test is also by its nature a quantitative test which makes it very valuable in structure stability comparisons in certain conditions. The highest value obtained for any soil was 9.2 p.s.i. at pF = 2 for soil No. 1. This is a low value and indicates that all the soils are of unstable structure under grazing conditions while at field capacity or wetter.

Three of the soils examined were similar to these found by Quinn (1958, 1959) to have a very stable structure by the wet sieving technique although

Table 3

Structure stability based on undrained shear strength (at pF = 2) and on the $\frac{P.L.}{F.C.}$ ratio

	1 Oldtown	2 Herbertstown	3 Ballinamore	4 Donegal	5 Ardagh	6 Macamore
Undrained Shear strength p.s.i.	9.2	6.4	5.1	4.4	2.8	4.6
$\frac{P.L.}{F.C.}$	0.92	0.68	0.65	0.56	—	0.64

experience had shown that these soils were very unstable under grazing conditions.

It seems therefore that the method suggested here has advantages in the comparison with structure stability of soils under pasture.

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SUMMARY

Because of special conditions of soil and climate large areas of Irish soils are subject to severe treading damage by grazing animals with consequent destruction of structure in the surface layers. It has not been possible to measure structure stability for these conditions by existing techniques and a new method is described. The method is based on the observations that structure damage by treading is caused by the sudden impact of the hooves of grazing animals and that such damage is possible while the soil moisture content is greater than the plastic limit. The water held between field capacity (defined as pF2) and the plastic limit must be removed by evapotranspiration and thus reflects the time required for the soil to become stable after wetting. The undrained shear strength gives a measurement of the resistance which the soils can offer to structure deterioration.

Various moisture values, the Atterberg limits and undrained shear strengths at saturation and at pF=2 were determined for six soils. From the figures obtained it was possible to classify the soils on the basis of their resistance to treading damage and this classification was in agreement with experience.

RÉSUMÉ

À cause des conditions spéciales de sol et de climat, de grandes étendues de sols irlandais sont sujetes à de sérieux dégats causés par le piétinement des animaux qui paissent, avec une destruction correspondante de la structure dans les couches de surface. Il n'a pas été possi-

ble de mesurer la structure de la stabilité pour ces structures par les moyens techniques existants et une nouvelle méthode est décrite. Cette méthode est basée sur les observations que les dégâts de la structure par piétinement sont causés par la pression subite des sabots des animaux qui paissent et que de tels dégâts sont possibles parceque l'humidité du sol est plus grande que la limite de plasticité. L'eau gardée entre la capacité au champ (définie comme pF2) et la limite de plasticité doit être éliminée par évapotranspiration et elle reflète ainsi le temps nécessaire pour que le sol devienne stable après humectation. La résistance au cisaillement à l'état non-drainé du sol donne la mesure de la résistance que les sols peuvent offrir à la détérioration de la structure.

Des valeurs variées de l'humidité, les limites Atterberg et la résistance au cisaillement à l'état non-drainé du sol, à la saturation et au pF = 2, ont été déterminées pour six sols.

Des données obtenues il a été possible de classifier les sols suivant leur résistance aux dégâts provoqués par piétinement et cette classification a été en concordance avec l'expérience.

ZUSAMMENFASSUNG

Grosse Flächen in Irland sind wegen besonderer Boden- und Klimabedingungen schweren Trittschäden seitens der weidenden Tiere ausgesetzt, welche die Zerstörung der Struktur in der Oberflächenschicht nach sich ziehen. Es war nicht möglich unter Zuhilfenahme der vorhandenen Verfahren die Strukturbeständigkeit in den gegebenen Verhältnissen zu messen und es wird eine neue Methode dargelegt. Sie fusst auf der Beobachtung der Tatsache, dass die Strukturbeschädigung durch Treten durch den plötzlichen Stoss der Hufen der weidenden Tiere verursacht wird, und dass eine solche Beschädigung nur dann möglich ist, wenn der Bodenwassergehalt die Plastizitätsgrenze überschreitet. Das zwischen Feldkapazität (als pF2 bestimmt) und Plastizitätsgrenze enthaltene Wasser muss durch Evapotranspiration entfernt werden und gibt so den erforderlichen Zeitraum wieder, damit der Boden nach dem Durchfeuchten wieder stabil wird. Die Scherfestigkeit in undräniertem Zustand ergibt das Mass des Widerstandes an, den die Böden gegen die Strukturbeschädigung leisten können.

Es wurden für sechs Böden verschiedene Feuchtigkeitswerte, Atterberg-Grenzen und Scherfestigkeiten in undräniertem Zustand und bei pF=2 ermittelt. Die erhaltenen Daten ermöglichten die Klassifikation der Böden auf Grund ihres Widerstandes gegen Trittschäden auszuarbeiten wobei diese Einteilung mit der Erfahrung in Einklang war.

DISCUSSION

J. DUNGLAS (France). La résistance au cisaillement (shear strength) représente-t-elle la cohésion pure (mesuré sous pression normale nulle) ou bien fait-elle intervenir le frottement interne (mesuré avec une pression normale déterminée)? Comment cette résistance a-t-elle été mesurée?

W. BURKE. The test carried out was in a triaxial machine with drainage prevented.

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INTERACTION OF SOIL COMPACTION, FORM AND RATE OF IRON APPLICATION ON THE GROWTH OF SOYBEAN VARIETIES[1]

A. P. MAZURAK, L. CHESNIN[2]

Mechanization of agriculture in the U.S.A. is one of the important factors responsible for the high productivity of arable land. However, soil compaction and its detrimental effects on plant growth have increased as the result of usage of heavy equipment on land. In addition, grading land for efficient irrigation and construction of bench terraces have increased the soil compaction problems.

The Bridgeport soil series in Nebraska appears to have iron deficiency associated with compaction. These soils are found in the Chestnut and Brown soil zones. They occur on the colluvial-alluvial slopes of the valley floor. Soil profiles have an immature development, are slightly alkaline in reaction, and have good drainage for medium-textured soils. The objective of this investigation was to study iron availability to soybeans grown on Bridgeport soil at different degrees of compaction.

PROCEDURE

Surface soil (Ap horizon) of a Bridgeport sandy loam for a greenhouse study was collected at the North Platte Experiment Station. Varying degrees of soil compaction were prepared with soil in cores of 945 cm^3 volume: very loosely (1.0 g/cm^3), loosely (1.3 g/cm^3), moderately (1.4 g/cm^3) and severely compacted (1.6 g/cm^3).

Moderately and severely compacted soil cores were prepared as follows: 400 and 500 grams, respectively, of cold soil (0°C) were placed in polyethylene bags with sufficient crushed ice to obtain a soil moisture content of 16 per cent (1/3-bar suction). The soil and ice were then permitted to thaw at room temperature. During thawing, the contents of the plastic bags were

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thorougly mixed. Soil was packed in three portions into a Proctor (1933) aluminum mold 10 cm in diameter, 11 cm in length with a 5 cm extended sleeve. On one portion of soil 2.3 kg Proctor hammer was dropped on soil surface in the mold 4 and 25 times from a height of 30 cms to obtain moderate and severe compaction, respectively. To the center 100 g of the soil of second portions which had been compacted in aluminum mold as previously described, nutrient variables had been added. Nutrients consisted of 0, 2, 4 and 8 lbs. of Fe per 2 million lbs. of soil in the DTPA and EDDHA chelate forms ; blanket treatments of 50 ppm of N, 2.5 ppm of S, 5 ppm of Zn, 15 ppm of K and 10 ppm of P were also added. A third portion of soil was added to mold and compacted as described.

Soil cores with very loose compaction were prepared as follows: Soil was treated with 0.1 per cent by weight of VAMA Krilium in solution, then air-dried and passed through a sieve with 9 mm diameter openings. For loose compaction, the air-dried soil was passed through a sieve with 2 mm diameter openings. A thin walled celluloid tube of the same dimensions as aluminum mold was used to form the soil cores. Nutrient variables were added to center of soil core.

All soil cores were placed in a polyethylene lined 1-gallon container on a 1-inch layer of quartz sand. Additional sand was placed around the intacted soil cores. The sand was compacted to a bulk density of 1.63 g/cm^3 by dropping the container on the floor 10 times. The celluloid tube was removed from the very loose and loose compacted soil cores.

Soybeans of Adams and Lincoln varieties were inoculated and planted separately on the top of each of these soil cores and covered with 1-inch quartz sand. All treatments were replicated 3 times. A stand of 3 plants per pot was obtained. All pots were watered to weight of the water retention capacity of the sand at 1/10 bar- plus 1/3 bar suction of soil whenever the near-wilting range of the plants was reached. The plants were harvested in the sixth week of growth at the initiation of flowering. Plant samples were weighed and analyzed for iron and manganese by X-ray emission spectrography using the procedures described by Chesnin and Beavers (1962).

RESULTS

One of the important soil properties of Bridgeport sandy loam is its low plastic index of 2.1 (table 1), which classifies the soil as slightly plastic. Content of 15 percent clay was just sufficient to give the soil stickiness and a small amount of plasticity.

The moisture content of the Bridgeport soil at which compaction occurs influences the bulk density (fig. 1). With the same compactive effort the bulk density was increased from 1.45 g/cm^3 at a moisture content of 15 bar suction to 1.61 g/cm^3 at 1/3 bar suction. Further increase in the moisture content of soil decreased its bulk density. A bulk density of 1,61 g/cm^3 represents a high impedance for root penetration as suggested by the low hydraulic conductivity value of < 0.001 cm/hr (table 1). In contrast, the hydraulic conductivity for a very loosely compacted core (1.04 g/cm^3) was 17 cm/hr.

Fig. 1. Influence of moisture content on the bulk density of a Bridgeport sandy loam after 75 impacts with a 2.3 kg Proctor hammer dropped from a height of 30 cms. Moisture contents of soil at 1/6—, 1/3—, and 15-bar suction are designated.

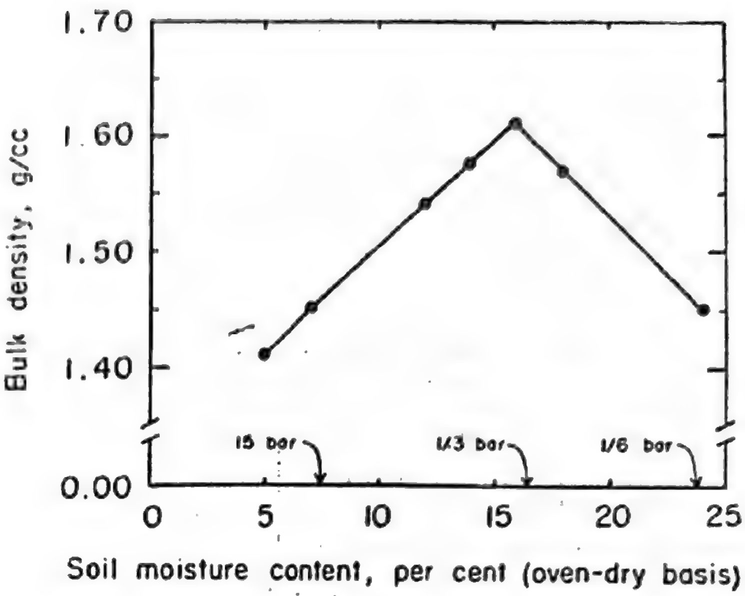

Table 1

Physical and chemical properties of the Ap horizon of a Bridgeport sandy loam

Particle size		
sand (> 50 μ diameter)	55	per cent
silt (50—2 μ diameter)	30	per cent
coarse clay (2—0.2 μ diameter)	7	per cent
fine clay (< 0.2 μ diameter)	8	per cent
Upper plastic limit	21.7	per cent
Lower plastic limit	19.6	per cent
Plastic index	2.1	per cent
Sticky point	20.0	per cent
Shrinkage from initial volume at sticky point to oven dryness	5	per cent
Hydraulic conductivity at		
very loose compaction (1.04 g/cm³)	17	cm/hr
loose compaction (1.27 g/cm³)	13	cm/hr
moderate compaction (1.35 g/cm³)	0.34	cm/hr
severe compaction (1.61 g/cm³)	<0.001	cm/hr
Calcium carbonate equivalent	<1	per cent
pH (1:1)	7.6	
Organic matter content	1.3	per cent
Available phosphorus content (Bray No. 2 extract)	66	ppm
Total nitrogen content	0.082	per cent
Cation exchange capacity for soil	15.9	me/100 g soil
Cation exchange capacity for <0.2 μ diameter particles (organic matter free)	84	me/100 g soil
Cation exchange capacity for 0.2—2 μ diameter particles (organic matter free)	32	me/100 g soil
Cations on exchange complex:		
Calcium	12.4	me/100 g soil
Magnesium	1.7	me/100 g soil
Potassium	1.9	me/100 g soil
Sodium	0.6	me/100 g soil

Predominant clay mineral of particles < 0.15 μ in diameter in the Bridgeport soil was montmorillonite. In the 0.15—2 μ diameter clay fraction, hydrous mica was the main mineral species along with small amounts of montmorillonite. Because of the small amount of clay present in the soil, the shrinkage property of Bridgeport soil in a puddled state was low — 5 per cent shrinkage from sticky point to oven dryness.

The genetic makeup of soybean plants influenced their growth on soil with different degrees of compaction (table 2). Yields were significantly

Table 2

Average dry matter production of Lincoln and Adams soybeans varieties as affected by source and rate of iron applied, and degree of soil compaction with their analysis of variance

Treatment		Dry matter production of soybeans tops, grams Iron applied in lbs. per 2 million lbs of soil.			
Source of iron	Degree of soil compaction	0	2	4	8
	Lincoln				
FeDTPA	Very loose	6.0	7.2	6.5	6.5
	Loose	7.4	5.4	6.5	7.1
	Moderate	6.0	6.6	6.1	6.0
	Severe	5.3	5.2	4.9	5.2
FeEDDHA	Very loose	6.4	6.8	6.2	6.6
	Loose	6.5	7.5	6.7	5.5
	Moderate	4.7	5.6	6.1	4.2
	Severe	5.7	5.2	5.1	4.4
	Adams				
FeDTPA	Very loose	6.7	6.4	4.0	6.2
	Loose	6.5	6.7	6.2	6.2
	Moderate	5.6	6.7	7.1	6.4
	Severe	4.1	5.1	5.1	4.8
FeEDDHA	Very loose	6.0	5.6	5.8	5.8
	Loose	6.3	6.2	6.2	5.8
	Moderate	6.2	5.8	4.7	3.4
	Severe	5.2	4.9	3.2	3.4

Source of variation	Degrees of freedom	Variance ratio	Level of significance
Total	191		
Variety	1	7.9	0.01
Source of iron	1	10.3	0.005
Rate of iron applied	3	4.0	0.025
Compaction	3	27.8	0.005

higher for Lincoln than for Adams variety. Iron applications in the form of DTPA resulted in more dry matter production than did the application of iron in the form of EDDHA. There was a tendency for application of two pounds of chelated iron per 2 million lbs. of soil to be optimum for plant growth; higher rates of iron application tended to depress vegetative growth.

Fig. 2. Influence of bulk density and rate of iron (FeEDDHA) application on the growth of Lincoln soybeans.

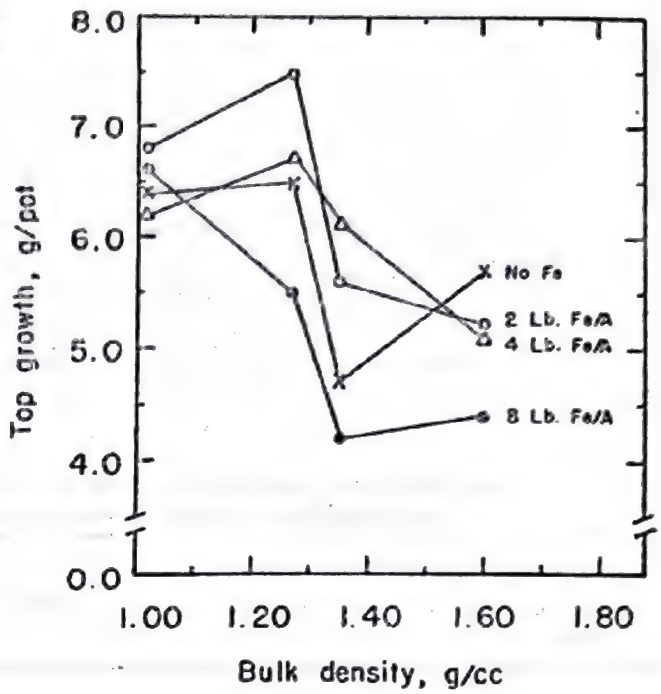

Table 3

Average content of iron in soybean tops as affected by variety, source and rate of iron applied, and degree of soil compaction

Treatment		Iron content of soybean tops, ppm			
		Iron applied in lbs. per 2 million lbs of soil			
Source of iron	Degree of soil compaction	0	2	4	8
		Lincoln			
FeDTPA	Very loose	121	128	112	128
	Loose	152	155	145	131
	Moderate	126	135	125	173
	Severe	128	121	137	121
FeEDDHA	Very loose	143	131	135	151
	Loose	106	123	126	158
	Moderate	121	149	169	125
	Severe	132	153	149	151
		Adams			
FeDTPA	Very loose	107	130	155	145
	Loose	133	151	116	128
	Moderate	131	140	163	143
	Severe	120	164	175	137
FeEDDHA	Very loose	136	138	155	124
	Loose	134	116	123	145
	Moderate	171	109	165	178
	Severe	135	137	158	192

Soil compaction affected the top growth of soybeans. Very loosely compacted soil (1.04 g/cm³) was not the best physical environment for the growth of soybeans (fig. 2). The loosely compacted soil cores (1.27 g/cm³) favored the top growth of soybeans only with an application of 2 or 4 pounds of iron per 2 million lbs. of soil. At the 8 lb. rate of iron application, dry matter production decreased with increasing degree of soil compaction. Applications of iron did not appear to alleviate the effects of severe soil compaction on soybean growth.

The source of iron and the degree of soil compaction did not influence the iron content of soybeans (table 3).

The Mn content of soybeans (table 4) was affected much more by increased soil compaction than was the iron content. The effect of compaction

Table 4

Average content of manganese in soybean tops as affected by variety, source and rate of iron applied and degree of soil compaction with their analysis of variance

Treatment		Manganese content of soybean tops, ppm			
		Iron applied in lbs. per 2 million lbs of soil			
Source of iron	Degree of soil compaction	0	2	4	8
		Lincoln			
FeDTPA	Very loose	59	62	65	63
	Loose	72	64	64	42
	Moderate	78	67	62	53
	Severe	75	68	68	63
FeEDDHA	Very loose	62	41	32	27
	Loose	67	37	20	21
	Moderate	86	28	21	20
	Severe	74	30	22	21
		Adams			
FeDTPA	Very loose	70	63	67	58
	Loose	62	57	55	39
	Moderate	76	56	54	50
	Severe	66	60	56	50
FeEDDHA	Very loose	68	43	28	21
	Loose	64	37	33	18
	Moderate	69	22	19	12
	Severe	64	24	20	18

Source of variation	Degrees of freedom	Variance ratio	Level of significance
Total	191		
Variety	1	27	0.005
Source of iron	1	960	0.005
Rate of applied iron	3	360	0.005
Compaction	3	6.6	0.01

was also evident in the chlorotic appearance of the plants especially at high rates of application of the iron. The FeDTPA applications did not reduce Mn uptake by the plants to the extent that FeDDHA applications did. High rates of iron application to the moderately and severely compacted soil increased the Fe: Mn ratio to values greater than 4 (table 5).

The distribution of the soybean roots in the quartz sand and soil cores was influenced by the degree of soil compaction. About 5 to 20 per cent of the roots by weight were found in the sand and 80 to 95 per cent of the roots grew in the very loosely and loosely compacted soil cores. In the moderately compacted soil cores, 30 to 40 per cent of roots grew in the sand. However, in the severely compacted soil cores 60 to 100 per cent of the roots were found in the sand. Roots adherred to the surface of the severely compacted soil cores, some roots penetrated only a few millimeters into the core.

Table 5

Ratio of Fe : Mn in soybean as affected by variety, source and rate of iron applied and degree of soil compaction with their analysis of variance

Treatment		Fe: Mn ratio in soybean tops			
		Iron applied in lbs. per 2 million lbs of soil			
Source of iron	Degree of soil compaction	0	2	4	8
		Lincoln			
FeDTPA	Very loose	2.1	2.1	1.7	2.0
	Loose	2.1	2.5	2.3	3.1
	Moderate	1.6	2.0	2.1	3.3
	Severe	1.7	1.8	2.0	1.9
FeEDDHA	Very loose	2.3	3.3	4.8	5.8
	Loose	1.6	3.7	6.4	8.0
	Moderate	1.4	5.3	8.2	6.4
	Severe	1.8	5.2	6.8	7.3
		Adams			
FeDTPA	Very loose	1.5	2.1	2.3	2.5
	Loose	2.2	2.4	2.1	3.3
	Moderate	1.7	2.5	3.0	2.8
	Severe	1.8	2.8	3.1	2.7
FeEDDHA	Very loose	2.0	3.2	6.2	6.0
	Loose	2.1	3.1	3.8	8.4
	Moderate	1.8	4.9	5.2	14.8
	Severe	2.1	5.8	8.1	7.7

Source of variation	Degrees of freedom	Variance ratio	Level of significance
Total	191		
Variety	1	8	0.005
Source of iron	1	300	0.005
Rate of applied iron	3	82	0.005
Compaction	3	11	0.005

DISCUSSION

Particle size characteristics of a soil affect its plasticity. Bridgeport sandy loam is a slightly plastic soil with a plastic index of 2.1. The response of root growth in severely compacted soil is probably associated with plastic properties of soil. Roots growing in a plastic soil of high bulk density will respond differently than in a non- to slightly-plastic soil. Roots are able to shift the particles in plastic soils as they penetrate the mass. In a non- to slightly-plastic soil, plant roots cannot penetrate the soil mass even though the soil may be moist. Wiersum (1957) observed that roots growing in a narrow glass tube filled with sand were not able to shift the sand grains.

In investigation of Bridgeport soil, soybean roots were not able to shift the soil particles in the severely compacted soil cores surrounded by sand. Most of the root growth occurred on the surface of the soil cores. The response of soil to penetration by soybean roots was not limited by moisture content because the soil had been packed near and maintained near the moisture content of 1/3 bar suction. The optimum bulk density value of the Bridgeport soil for plant growth appears to be 1.3 g/cm^3. An increase of 0.1 g/cm^3 in the bulk density of the soil from 1.3 g/cm^3 greatly reduced the dry matter production of soybeans.

The very loose compaction treatment (1.04 g/cm^3) tended to reduce the growth of soybeans as compared with the loose compaction (1.27 g/cm^3.). Evidently, the soybean roots did not have sufficient contact with the soil particles for nutrient uptake to produce optimum growth. Miller and Mazurak (1958) obtained poor growth of sunflowers in a medium with large pores. Passioura and Leeper (1963) reported that compaction of very loose, manganese deficient soils in Australia increased the growth of oats. Compaction of very loose soil increased the root-soil contact area and influenced the oxidation-reduction equilibrium in the soil.

Miller and Mazurak (1958) noted that growth response of plants to the changes in the physical condition of soil was parabolic. Tret'yakov and Galitskii (1963) show that this type of parabolic response occurred with varying degrees of compaction with large and small volumes of soil. Bunt (1961), Flocker and Nielson (1960), Kanarake and Taler (1962), Rosenberg and Willits (1962) and others found that the plant growth response to increasing soil bulk density may increase, decrease or indicate a parabolic growth response. Differences in growth responses were probably due to the incomplete design of the experiments which did not cover a wide range of soil bulk density values.

In the investigation with soybeans and in another experiment with corn (unpublished) parabolic growth responses were obtained with soil bulk density, provided other factors did not limit growth. Should plant growth decrease with increasing soil bulk density without showing a parabolic response over a wide range of bulk density values, there may be another limiting growth factor. With an application of 8 lbs. of iron per 2 million lbs. of soil (fig. 2) soybeans did not show the parabolic growth response with increasing bulk density. The high rate of iron application disturbed the Fe:Mn

ratio in the leaves resulting in severe chlorosis and stunting of the plants. Compaction studies covering a wide range of bulk densities may reveal the existence of other limiting factors for plant growth.

Genetic factors influence plant responses to varying degrees of the physical condition of soil. The Lincoln variety of soybeans responded better to increasing soil compaction than did the Adams variety. However, Lincoln soybean plants appeared to be under stress as indicated by discoloration and lesions of the leaf petioles when grown on moderately to severely compacted soils. Fulton et al. (1961) noted that the incidence of infection with *Phytophthora megasperma* in soybeans increased when both the surface and subsurface soils were increased in compaction from 1.2 g/cm^3 to 1.5 g/cm^3.

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SUMMARY

Cylindrical cores of soil 10 cm in diameter and 11 cm in length representing four degrees of compaction (1.0 to 1.6 g/cm^3) were surrounded by quartzs and in 1-gallon containers. Two varieties of soybeans were planted. Two forms of iron chelates (DTPA and EDDHA) at rates of 0, 2 cm^3 4 and 8 pounds of iron per 2 million pounds of soil were added along with blanket treatments of other nutrients to the center of the soil cores. Increasing the degree of soil compaction affected soybean growth. Loosely compacted (1.3 g/cm^3) soil cores produced more dry matter by flowering time than did the very loosely (1.0g/cm^3) and moderately compacted soil cores. The severely compacted (1.6 g/cm^3) soil cores produced the least amount of dry matter.

Two pounds of iron as the DTPA form per 2 million pounds of soil tended to be the optimum rate of application. The FeDTPA applied to the soil was superior to the FeDDHA as a source of iron for the growth of soybeans in this study. Discoloration of petioles of soybeans indicated nutritional disturbances in Lincoln soybeans grown on severely compacted soil but not in the Adams variety. However, the dry matter production was greater for the Lincoln variety than the Adams variety. The manganese content of soybean leaves was affected more by soil compaction than was the iron content of the leaves. The Fe : Mn ratio of plants was greater than 4 with the moderately and severely compacted soil when 2, 4 or 8 pounds iron in the form of EDDHA were applied per 2 million pounds of soil.

RÉSUMÉ

Des échantillons de sol cylindriques, ayant un diamètre ed 10 cm et une longueur de 11 cm, représentant 4 compacités diverses (1,0 à 1,6 g/cm.^{3}) ont été entourés de sable à quartz dans un récipient de 1 gallon. On a planté deux variétés de soya. On a introduit, au centre des monolithes de sol, deux formes de chelate de fer (DTPA et EDDHA) en doses de 0, 2, 4 et 8 lb. (pounds) de fer pour 2 millions lb. (pounds) de terre ainsi que les autres substances nutritives, en quantité égale pour tous les traitements. Le degré de compacité du sol a influencé la croissance des plantes de soya. Les échantillons légèrement compactés (1,3 g/cm^3) ont produit plus de substance sèche à l'époque de la floraison que les échantillons de sol très légèrement (1,0 g/cm^3) et modérément compactés. Les échantillons de sol le plus fortement compactés (1, 6 g/cm^3) ont produit la plus petite quantité de substance sèche.

Deux lb. (livres) de fer en forme de DTPA pour deux millions lb. (livres) de sol ont été le taux d'application optimum. Dans cette recherche le FeDTPA appliqué au sol a été supérieur au FeEDDHA en tant que source de fer pour la croissance du soya. La décoloration des pétioles de soya a marqué des troubles nutritifs dans la croissance pour la variété Lincoln de soya sur des sols fortement compactés et non pour la variété Adams. La teneur en manganèse des feuilles de soya a été plus influencée par la compaction du sol que la teneur en fer des feuilles. Le rapport Fe :Mn des plantes a été plus grand que 4 pour les sols modérément et trés compactés lorsqu'il y a eu une application de 2, 4, et 8 lb. (livres) de fer en forme de EDDHA pour deux millions de lb (livres) de sol.

ZUSAMMENFASSUNG

Zylindrische Bodenmonolithe von 10 cm Durchmesser und 11 cm Länge, vier Dichtheitsstufen (von 1,0 bis 1,6 g/cm^3) darstellend, wurden mit Quartzsand in Gallonbehältern umgeben. Zwei Sojaarten wurden gepflanzt. Zwei Eisenchelatformen (DTPA und EDDHA), in 0, 2,4 und 8 Pfund Eisengaben per 2 Millionen Pfund Boden, wurden unter Anwendung einer aus anderen Nährstoffen bestehenden Decke zum Zentrum der Bodenmonolithe hinzugefügt. Mit der Verstärkung der Bodendichtheitsstufe wurde das Pflanzenwachstum der Sojabohnen beeinträchtigt. Locker verdichtete (1,3 g/cn.^{3}) Bodenmonolithe entwickelten mehr Trokkensubstanz in der Blütezeit als sehr locker (1,0 g/cm.^{3}) verdichtete Bodenmonolithe. Die besonders stark (1,6 g/cm^3) verdichteten Bodenmonolithe entwickelten die geringste Menge von Trockensubstanz.

Zwei Pfund Eisen in der DTPa-form per 2 Millionen Pfund waren die optimale Anwendungsdosis. Die dem Boden angetragene FeDTPA erwies sich der FeEDDHA überlegen, als Eisenquelle für die Förderung des Wachstums der Sojabohnen in dieser Untersuchung. Die Verfärbung der Sojabohnenblattstiele deutete Ernährungsstörungen im Wachstum der Lincoln Sojabohnenart auf sehr stark verdichtetem Boden an, aber nicht bei der Adamsabart. Jedenfalls, die Trockensubstanzproduktion war grösser für die Lincolnabart als für die Adamsabart. Der Mangangehalt der Sojabohnenblätter war mehr als der Eisengehalt derselben Blätter durch Bodenverdichtung beeinflusst. Das Fe : Mn Mengenverhältnis der Pflanzen war grösser als 4 mit dem mässig und sehr stark verdichteten Boden bei der Anwendung von 2, 4 oder 8 Pfund Eisen in dor EDDHA Form per 2 Millionen Pfund Boden.

DISCUSSION

J. A. CURRIE (U.K.). I am always disturbed when I see the term "bulk density". This experiment is concerned with root penetration. Did you measure the associated reduction of the pore size when the soil was compacted? This merely is the relevant soil parameter here.

A. P. MAZURAK. We have not measured the pore size distribution in soil for this experiment. We have measured the pore size distribution in other samples of similar soils.

S. A. TAYLOR (U.S.A.). What was the moisture content pf this soil at $^1/_3$ bar and at 15 bar pressure difference across a porous membrane when compacted to each of the 4 bulk densities used?

A. P. MAZURAK. The severely and moderately compacted soils were compacted at 1/3 bar which gave the maximum bulk density. The severely compacted soil core had more water than did the moderately compacted core. The amount of water content for very lossely compacted soil core was the least.

S. A. TAYLOR. Are your results related to the speed of water uptake and availability, both of which are influenced by hydraulic conductivity and water potential?

A. P. MAZURAK. Hydraulic conductivity of soil core was markedly reduced by compaction. We don't think the water uptake was a marked factor in availability to plant since part of roots were in sand and could absorb water.

A. CANARACHE (Rumanian People's Republic). Taking into account that increasing bulk density affects not only yields directly but also moisture relations and air content — have you performed some determinations on air content?

A. P. MAZURAK. We have calculated the moisture air contents of soil core. But these results are made complicated by the sand layer surrounding the soil core. We think that air content for roots was sufficient except for the severely compacted core and to certain extent for the moderately compacted core.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

I+VI. 18

THE PEDOMORPHOLOGICAL ASPECTS OF MECHANICAL SOIL IMPROVEMENT

K. VAN DER MEER, J. R. WILLET [1]

INTRODUCTION

By „soil improvement" is meant here the carrying out of drastic soil treatments, often to great depths, which will result in a permanent change in the soil profile, with a view to improving the production possibilities of the soil.

In this regard the object may be:

a) to break or turn impermeable layers (loam, cemented sand, compressed peat), which hamper vertical water movement and root development);

b) to bring up to the surface material from the subsoil, which has more favourable properties than those of the top soil, as regards texture, calcium-carbonate content and workability.

Many of such soil improvements, often combined with reallocation work have been carried out in our country.

In former times, these soil improvements were done manually but during the last 15 years, mechanized execution has become predominant. This however, sometimes entails serious problems as regards the direct results of the work. Into the causes of these problems we will go a little more deeply in the following pages.

The following points will serve to indicate the difference between the old manual methods and the mechanized ones of to-day.

a) the mechanized work is done with great rapidity. Mistakes are not noticed or rectified in time;

b) work is often done under conditions which are not ideal (wet). When a machine is available at a certain moment often the work cannot — owing to its planning — be postponed till a more favourable occasion. It must be borne in mind that annual rainfall in the Netherlands exceeds evaporation by an average of 200 mm (8 inches);

c) as the force exerted by mechanized tillage is so much greater than in manual labour, the soil is naturally disturbed to a far greater extent;

d) most machines ride over the surface of the ground and cause vibrations which are communicated to the soil, all of which are unfavourable to its structure.

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UNFAVOURABLE RESULTANT REACTIONS

The desired profile changes are attained by mechanized treatment. However, unfavourable reactions often result which seriously diminish (at any rate at first), its beneficient effect. In extreme cases, the land cannot be used for the first few years after treatment.

These unfavourable reactions can be described as follows:

1) the soil is weak and soft, is saturated with water, puddles form on it. Normal tillage is impossible;

2) sown or planted crops may sometimes take root but rot after a time and give very little orno yield;

3) mechanized harvesting is impossible, because the soil is much too soft and wet.

It has long been known that the above situation particularly arises under the following conditions:

a) when the material treated partly or wholly consist of aeolian sand and marine deposits of a fine-sandy, loamy nature;

b) when high ground water tables occur during or shortly after treatment.

As regards this latter point, it should be pointed out that practically all soils which enter into consideration for soil improvement in Holland have a hydrologically low situation, i.e. winter ground water tables of less than 1 m.

Attempts to drain land, the conditions of which are so bad, after it had been brought into the unfavourable conditions mentioned above, by means of tube drainage, mostly results in failure. The drains remove little or no water, as the soil will not release it. Renewed treatment of the soil generally leads to a deterioration of conditions. Recovery generally occurs after a certain period of time, which may be speedy in the case of a grass cover (meadows).

The terrain then regains its firmness, the puddles disappear, and the possibility of tillage increases.

As the symptom described above is agriculturally inacceptable, a study was made in view of getting to know more about its causes. This study mainly concerned aeolic sand deposits in the eastern part of the Netherlands.

DESCRIPTION OF THE RESEARCH MADE

The research was made in aeolic sands of a rather fine texture underlying a peaty surface soil of poor quality. By means of deep-ploughing this sand had been brought to the surface. The horizontal layering in the original soil profile was changed into a more or less vertical one, showing alternative beams of sand and peat (fig. 1). Investigations were also made in the same aeolic sand after roto tillage and digging.

The various items of the study will now be described here.

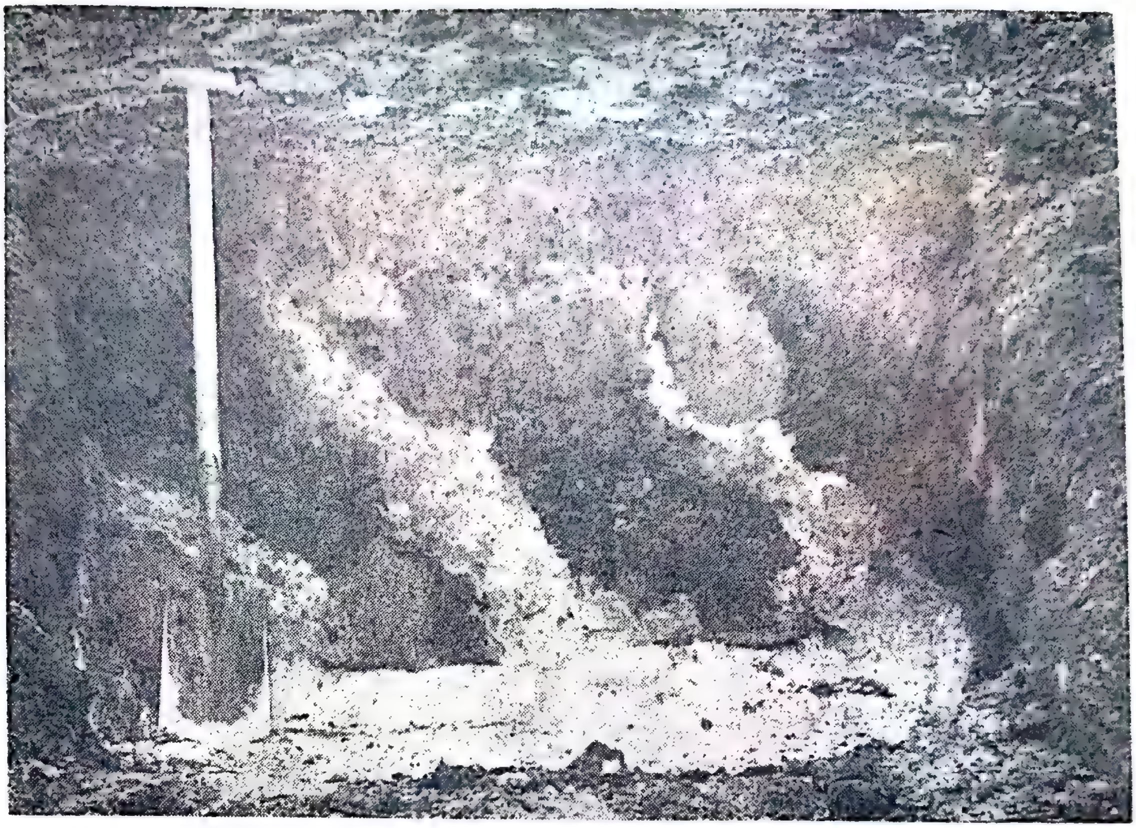

Fig. 1. General aspect of a deeply plowed soil.

Grain-size distribution and humus

Some grain-size analyses have been given in table 1.

From figure 2 it will be seen that the relations between the results of tillage are extremely wide if the fraction 0—50 μ is taken as a parameter, but relati-

Table 1

Grain-size distribution of some improved soils

Object *	Grain-size distribution in weight per cent mineral matter of the following fractions in microns							U	Results of tillage
	0—2	2—16	16—50	50—105	105—150	>150	0—50		
A	2.5	1.0	13.0	38	13	33	16.5	137	good
A	2.0	1.0	3.5	37	28	29	6.5	100	moderate
A	3.5	1.5	11.0	28	24	32	16.0	116	poor
B	1.5	1.0	16.0	14	20	48	18.5	126	good
B	1.0	0.2	6.0	25	24	45	7.2	100	good
C	3.0	1.0	5.0	38	31	21	9.0	107	good
C	2.5	0.5	3.0	36	33	24	6.0	105	good
D	4.5	1.5	6.0	21	24	42	12.0	100	poor
D	5.0	0.5	15.0	20	20	40	20.5	144	poor
Dune sand (Flower-bulb soil)		1.0	0.2	0.8	11	87	1.2	54	Never difficulties

* The indications of the objects are the same as in tables 2 and 3.

vely close when the fractions 0—16 μ and 0—2 μ are taken into consideration.

One might say that below 4 per cent of the fraction 0—2μ few difficulties are met with, taking into account the fineness of the sand fraction ($U = 100$—145).

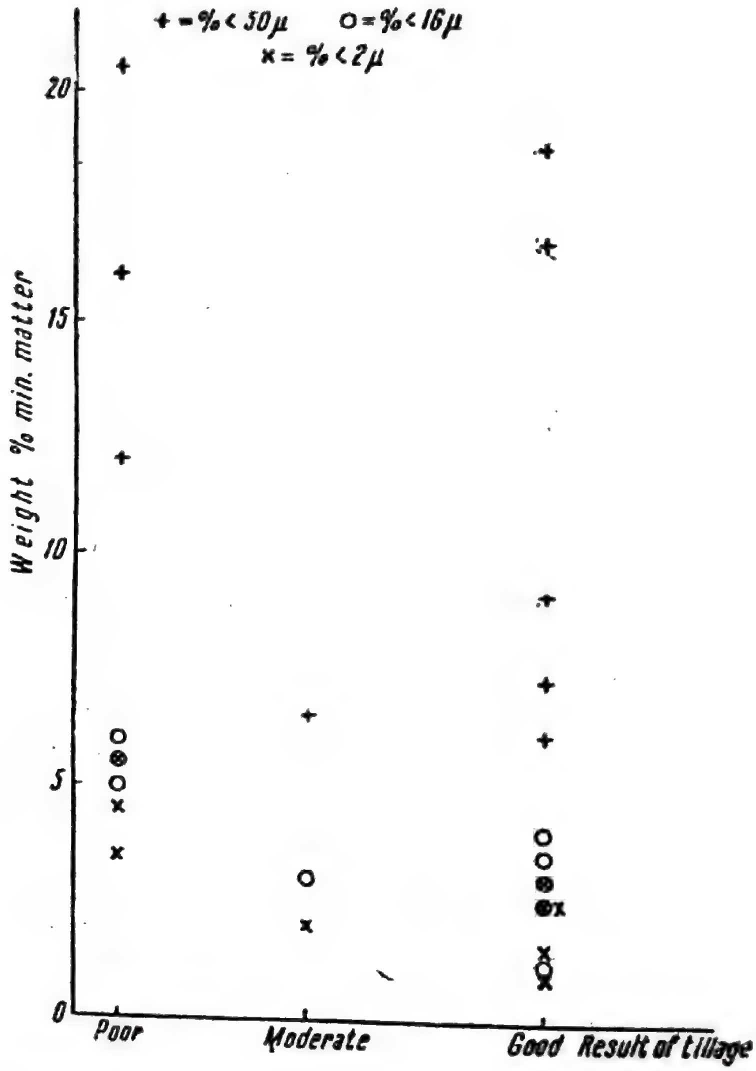

Fig. 2. Relations between texture and result of tillage.

Just as fine mineral particles, organic matter also forms part of the fine fraction. Soils having a certain humus content may also present difficulties. At present, however, little attention can be devoted to this side of the question. One has the impression though, that the form of humus does play a role here.

Hydraulic conductivity

Hydraulic conductivity and changes in it have always been regarded as one of the factors responsible for possible unfavourable results of deep tillage.

The connection between permeability and grain size was i.a. investigated by Fahmy (1961) in the case of marine sands with varying clay content, in which study it emerged that with samples treated in the same way, an increasing clay content accompanies decreasing hydraulic conductivity.

With coarse sand (U = 43), the decrease in the K-value was proportionally greater that with fine sand (U = 205).

It further appeared that the way of pre-treating the sample exercised a prevailing influence on permeability.

Mixing with 12 per cent clay in aggregate form resulted in a hydraulic conductivity which was 7 to 10 times as high as the same addition with a kneaded sample. In the case of natural (undisturbed) samples with more than 7.5 per cent clay, hydraulic conductivity can rise ten-fold after drying the sample. According to the results of Koenigs (1964), an increase in the K-value took place by drying and freezing.

Puddling caused a lowering of the permeability.

The Fahmy's results agree well with our investigation of aeolic sand soils. A soil tilled at field capacity (object A in table 1) had a hydraulic conductivity of 0.10 m/24 hours. After tilling in a saturated state, the K-factor became immeasurably small.

Koenigs (1964) found that the moisture content at which the sample had been homogenized was of great influence on the hydraulic conductivity. When a certain moisture percentage was exceeded low K-values occur.

Hydrological situation

Nearly all the areas where soil improvement is resorted to in the Netherlands are hydrologically speaking low-lying, i.e. they have high ground water tables, varying between 0 and 2 m below soil surface.

Ditches or drains provide drainage. As has been shown, in this respect, permeability often decreases as a result of tillage. This will cause the required difference in pressure head *(M)* for the ground water flow to increase with a resulting deterioration of the drainage situation (In other words the welling up of the ground water between ditches or drains becomes greater) (fig. 3).

Deep ploughing causes a tendency to vertical layer formation, which increases the horizontal flow resistance in the soil.
An unfavourable factor in this regard is that lots are ploughed in the length, so that the water is impeded on its shortest way (right across the plot) to the ditch. This has no injurious effect as long as there is a sufficiently thick permeable layer under the depth ploughed. It has quite another effect when poorly permeable layers (e. g. boulder clay) occur (fig. 4).

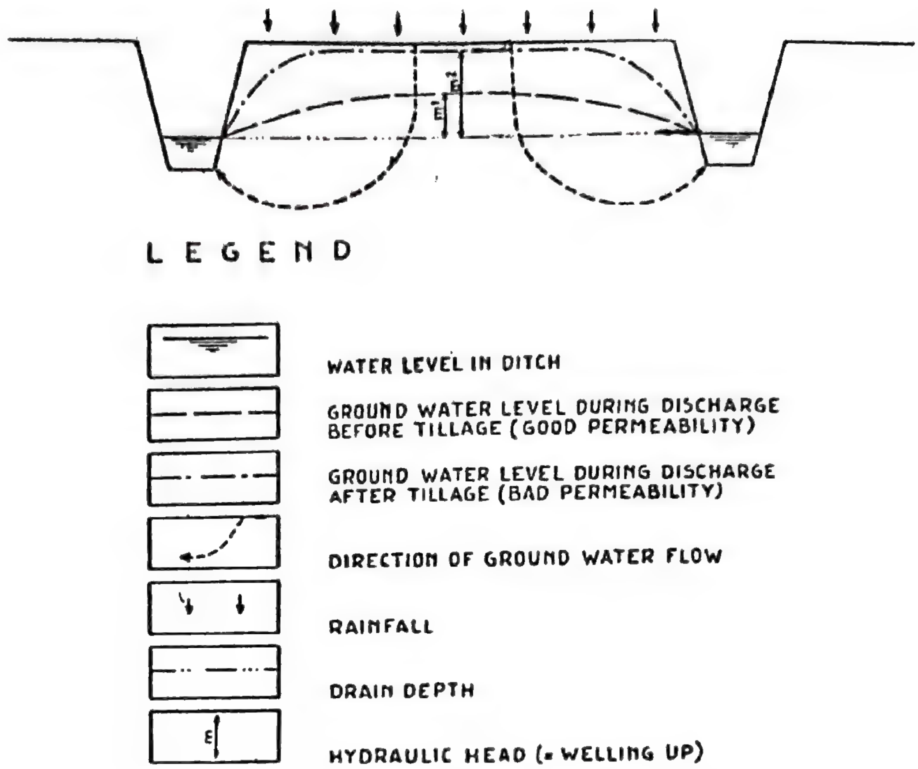

Fig. 3. Drainage of soil before and after tillage.

When soil improvement is accompanied by the widening of the lot, whereby water passages are filled in, a greater distance between ditches occurs. Unless there are other counteracting measures (tile drainage) this will cause drainage conditions to deteriorate. When soil conditions (as was so often the case) have a ditch interval which hardly sufficiently guarantees drainage, then the filling in of ditches will lead to a surfeit of water with all its troublesome consequences. The parcels of land in the dug off peat moor area have a breadth of approx. 70 m.

By filling in a ditch one gets a breadth of 140 m. According to a drainage study, by Hooghoudt's method, the distance between drains would have to be 30 to 40 m for the case in question after treatment. Thus a troublesome surplus of water would be created without drainage.

As regards the relationship between the hydrological situation and the failure of soil improvements, it can be affirmed that the bad objects do always have high ground water levels compared with the good.

One gets the impression, that it is a question of interaction. High ground water levels promote deterioration of structure (working under wet conditions), whereby failure occurs sooner.

On the other hand the decrease in permeability as a result of structural decay leads to higher ground water levels.

The great difficulty in this regard is, that pipe drainage generally offers no improvement, because the water does not enter the drain pipes unim-

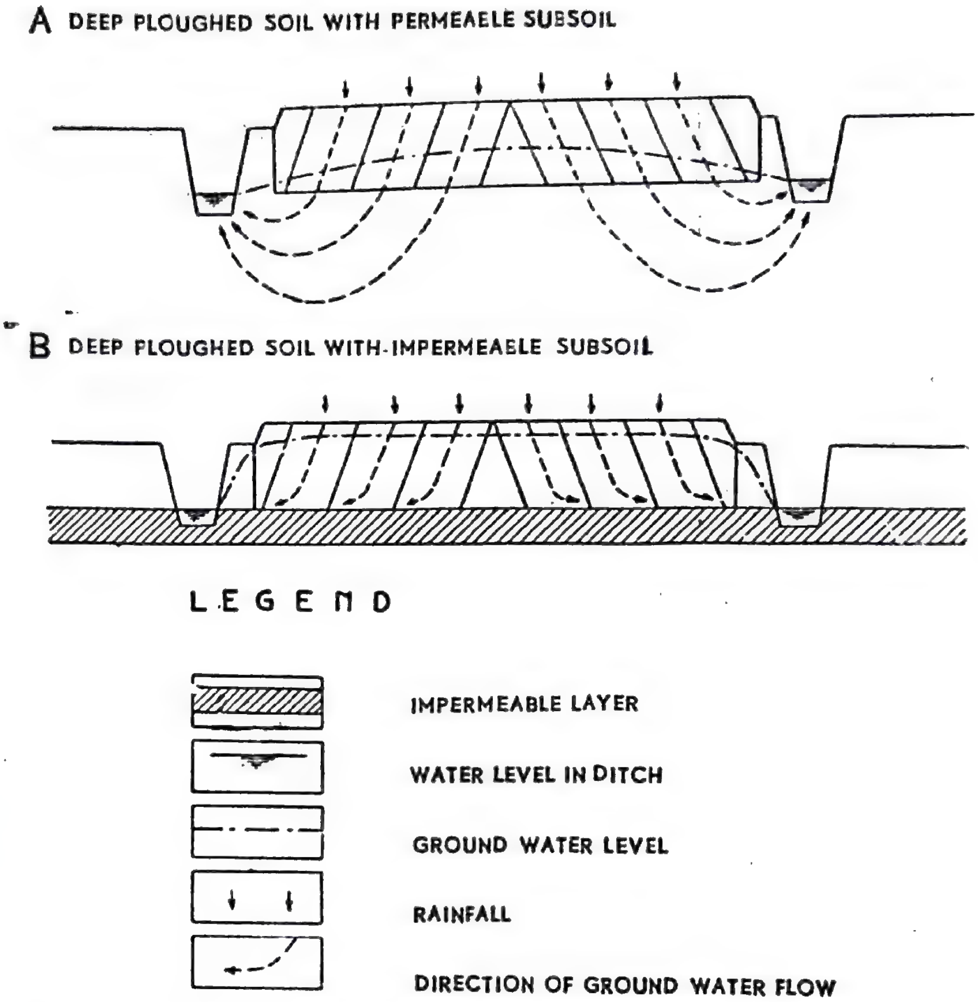

Fig. 4. Drainage of deeply plowed soils with permeable and impermeable subsoils.

peded. Cavelaars (1962) has described this phenomenon. Besides, in the flow pattern, the explanation must be sought in a loss in permeability in the vicinity of the drain pipe. This may be the result of a mechanical soil improvement which has already been carried out, or of mechanized drainage which is in principle, a local, deep soil treatment (table 2).

Structure stability

Boekel (1963) gives a measure of the sensibility of the slaking of soil types, the difference between weight per cent moisture at upper plastic limit and at pF = 2.0. When this difference is smaller than 3 weight per cent, he considers the soil in question sensitive to dissipation.

It was tried to quantify the structure stability of the tilled soil in the same manner, the results of which are given in table 2. It appeared that pF = 2.0

Table 2

Moisture contents of some improved soils

Object*	Location of sample	Soil layer	Treatment	Weight in percent at: Upper plasticity limit	pF 2.0	pF 2.3	Difference between upper plastic limit and pF 2.3	Effect of treatment
A	1	tilled layer (top)	deep ploughing	35.8	29.5	23.1	12.7	good
		tilled layer(middle	deep ploughing	26.1	13.1	8.5	17.6	good
	2	tilled layer (top)	deep ploughing	29.5	23.5	18.7	10.8	moderate
		tilled layer(middle	deep ploughing	25.9	13.5	9.9	16.0	moderate
	3	tilled layer (top)	deep ploughing	36.8	42.0	35.0	1.8	poor
		tilled layer(middle)	deep ploughing	23.3	17.0	15.1	8.2	poor
E		tilled layer	roto tillage	30.4	27.3	21.0	9.4	good
		tilled layer	roto tillage	31.7	21.7	15.9	15.8	good
		tilled layer	roto tillage	30.9	21.5	16.4	14.5	good
		tilled layer	roto tillage	34.6	26.6	18.7	15.9	good
		tilled layer	roto tillage	28.9	17.7	12.5	16.4	good

* Indications of objects and the location of samples are the same as in tables 1 and 3.

for the soils treated was not a good measure, but that the difference between weight per cent moisture at upper plastic limit and pF = 2.3 showed a close relationship to the results of treatment. With one exception, all differences for very successful objects were above 10 per cent, the bad ones under. Moreover, the differences in the top soil are always much lower than under it. This might be the result of levelling and subsequent soil treatment. In the case of another sample (top soil sample location 3) the difference is practically nil, in other words the soil loses its stability already at field capacity. It was a bad part that was concerned here.

The figures also show that one has to be extremely careful in deep ploughing with water tables higher than the depth of tillage. In that case sand saturated with water from under the groundwater is ploughed up. This sand is saturated in undisturbed circumstances. Although tillage will cause the total pore volume to increase, and in the meantime the pF to rise, the moisture content after tillage will be above field capacity (pF = 2.3) and most probably above the upper plastic limit of the material, so that ploughing such sand entails immediately demonstrable risks of flowing away. In hydraulic conductivity measurements it appeared during percolation that there was a distinct displacement of fine particles. This was visible by the occurrence of layer forming (fig. 5). From this it appears that changes can occur in the structural arrangement of the material, as a result of ground water flow. It is certain

that this exercises an influence on permeability. For when the fine fraction in certain layers heaps up (as can be seen in fig. 5), there is the chance that the sand skeleton in those layers becomes partly or wholly choked by small particles. The impression exists that in practice this mechanism is also active.

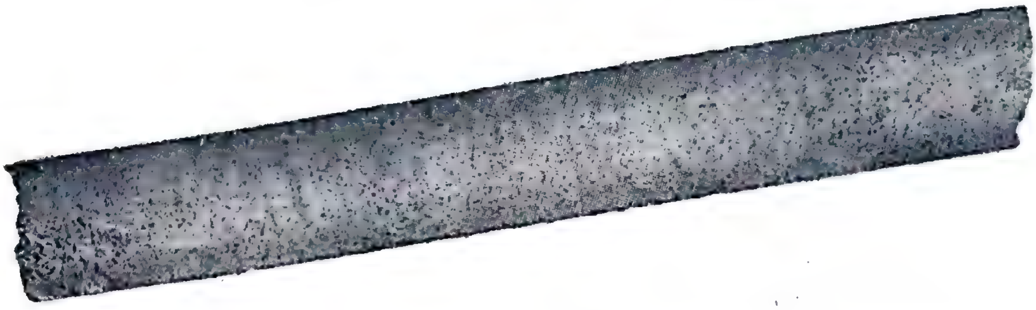

Fig. 5. Layer forming in sandy soils during percolation of water.

Fahmy (1961) also experienced troubles from layer formation in his investigations on hydraulic conductivity, which were responsible for changing results. He combated this phenomenon by percolation with a $CaCl_2$ solution. These layers may occur horizontally at a certain depth or concentrically around the tile drains. This latter phenomenon can also be caused by a filtering effect of the filter material (glassfibre or peat) around the tile drains. The extremely high flow resistances sometimes measured around drain tubes might be explained by this migration of fine fraction deposited in the surroundings of the drain pipe. This point will have to be further investigated (Cavelaars, 1962).

Pore distribution

Changes of structure and thus of pore distribution take place in soils which have been treated. It is quite natural to suppose that structural deterioration must be expressed in pore distribution. Thereby it will appear that the total pore volume gives a misleading picture. The assumption therefore, that the hydraulic conductivity of the soil will increase with porosity does not appear to have been confirmed.

The pore size distribution can be read from the pF-curve provided that no settling occurs during the determination. From table 3 it can be seen that the volume of large pores in the objects with unfavourable results is small (average 16,3 per cent between pF=0.4—2.3). Although the total pore volume (pF=0.4) is much larger after treatment (samples 4 and 5) the percentage of large pores decreases after tillage. By the puddling action of mechanized treatment at high moisture contents the fine material is suspended in the water between the sand grains, in this way lowering the diameter of the pores. It is clear that this effect has more influence when the clay content increases.

Table 3

Pore size distribution of some improved soils

Object*	Location of sample	Soil layer	Treatment	Volume percent moisture at pF 0.4	2.0	2.3	Tension free pore volume (pF 0.4—2.3)	Effect of treatment
A	1	tilled layer (top)	deep ploughing	56.5	34.5	26.9	29.1	good
		tilled layer (middle)	deep ploughing	39.6	20.9	13.6	26.0	good
	2	tilled layer (top)	deep ploughing	48.0	32.5	25.8	22.2	moderate
		tilled layer (middle)	deep ploughing	34.3	23.5	17.3	17.0	moderate
		tilled layer (top)	deep ploughing	56.5	48.2	40.4	16.1	good
		tilled layer (middle)	deep ploughing	36.2	28.7	25.5	10.7	poor
D	4	67—75 cm	none	35.3	26.9	12.2	23.1	—
		65—75 cm	none	34.8	26.4	12.1	22.7	—
	5	85—95 cm	dug out and used in raising	47.5	36.4	27.0	20.5	poor
		85—95 cm		45.4	35.7	27.6	17.8	poor
E		tilled layer	roto tillage	54.6	32.8	25.2	29.4	poor
		tilled layer	roto tillage	50.4	28.6	21.0	29.4	good
		tilled layer	roto tillage	51.8	27.3	20.9	30.9	good
		tilled layer	roto tillage	57.4	30.0	21.1	36.3	good
		tilled layer	roto tillage	49.9	23.5	16.7	33.2	good

* The leters indicate the same farms as those in tables 1 and 2.

A comparison with the paragraph on "hydraulic conductivity" shows that a correlation must exist between the big pore content and hydraulic conductivity (table 3).

DISCUSSION OF THE RESULTS

Unfavourable resultant reactions are met with, when the treated soil has a certain clay percentage and when tillage is carried out under wet conditions, i.e. with groundwater tables higher than the depth of tillage.

The cause must be sought in a loss of structure stability. The fine fraction (clay and silt) goes into suspension, the volume of large pores and the hydraulic conductivity are reduced. The weak condition of the soil can be explained by the high total pore volume after tillage, the high moisture content and thus the low stability of the soil.

Drying and freezing result in an increase in permeability, probably connected with reaggregation of the fine fraction. In natural soil, biological action also probably plays a part in the recovery (root action, soil fauna).

PRACTICAL CONCLUSIONS

In seeking a solution to the various problems encountered, attention should first be directed towards their avoidance. This means that in the case of sensitive soils extra care must be taken.

The granular composition can serve as an indication here. Moreover, adequate drainage during and after treatment is a condition for its success.

Based on the various data, the following can be taken as a practical norm for sensitive soils: a ground water level which is at least 20 cm deeper than the depht of tillage. This means a ditch level or a drain depth of 40 to 80 cm below working depth. Attention must be paid to surface drainage after soil treatment. It is advisable not to trust completely too deep drainage via the ground water. A convex soil surface and necessary temporary ditching are advisable.

The right choice of crop and method of cultivation are of importance for the first few years.

Efforts must be made to avoid disturbance of the soil as much as possible. Seeded grassland would be ideal the first year. Where this is impossible (for agro-economic reasons) grain but no root crops (beets, potatoes) should be grown during the first few years. It is important that the land should have a covering in winter, thus a winter crop or stubble.

Good fertilizing is necessary, in which regard it must be borne in mind that extra applications are necessary if good results are to be obtained.

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SUMMARY

In the Netherlands efforts are being made to give large areas of reclaimed peat land with sandy subsoil greater agricultural pcssibilities by means of deep ploughing. In practice, it has now appeared that in some areas results leave something to be desired and that the deeply ploughed soil gives evidence of unfavourable hydrological characteristics. Investigation on several parcels has shown that relatively fine, slightly clay-containing sands, influenced by

unfavourable drainage conditions, come into a very unstable structural state. This and the mechanical peptization of the clay fraction causes the liquid limit of the soils to be exceeded, whereby the whole of the parcel treated comes, as it were, in a state of unripened mud, with all the unfavourable agricultural characteristics concerned.

RÉSUMÉ

L'on s'efforce aux Pays-Bas de donner une meilleure valeur agricole aux sols tourbeux à sous-sol sableux qui sont mis en culture. Dans la pratique, il s'est avéré en certains cas que les résultats laissaient à désirer et que le sol profondément labouré avait alors des caracteres hydrologiques défavorables.

Un examen des diverses parcelles a montré que, sous l'influence d'un drainage insuffisant après le labour profond, les sables relativement fins, légèrement argileux, possèdent un état structural labile. Ceci, joint à une peptisation mécanique de la fraction argileuse conduit au dépassement de la limite supérieure de plasticité des sols et toute la parcelle travaillée donne l'impression d'une étendue de boue qui n'a subi encore aucune maturation, possédant les mauvaises propriétés agronomiques liées à cet état.

ZUSAMMENFASSUNG

In den Niederlanden wird versucht die landwirtschaftlichen Möglichkeiten grosser Gebiete bereits früher urbar gemachter Moorböden mit sandigem Untergrund durch Tiefpflügen zu vergrössern.

Es hat sich in der Praxis ergeben, dass die Ergebnisse auf mehreren Flächen nicht einwandfrei sind und dass sich dort der Wasserhaushalt der tiefgepflügten Böden als weniger günstig erzeigt. Untersuchungen auf verschiedenen solcher Flächen ergaben, dass sich in verhältnismässig feinen, leicht tonhaltigen Sanden unter ungünstigen Entwässerungsverhältnissen sehr unstabile Gefüge entwickeln. Hierdurch und infolge einer mechanischen Dispersion der Tonfraktion wird die Fliessgrenze des Bodens überschritten und der Boden der ganzen Fläche gerät sozusagen in einen ungereiften Zustand mit allen zugehörigen ungüstigen landwirtschaftlichen Eigenschaften.

DISCUSSION

W. H. VAN DER MOLEN (Netherlands). Is there any influence of the circumstance under which the deep tillage operation is executed?

K. VAN DER MEER. In general deep plowing under dry circumstances will give the best result. Under dry circumstances is meant: dry weather conditions and deep drainage. An exact quantitative answer on drainage depth cannot be given at this moment. It is known that the drainage is of the utmost importance and practical advice with a certain safety margin can be given, but the exact drainage depth and influence of capillary zone has still to be studied in further detail.

PLANT PHYSIOLOGICAL PRINCIPLES OF EFFICIENT SAND MELIORATION

S. EGERSZEGI [1]

High and reliable crop yields on sand or even shifting sand of low fertility can be obtained by crop production on a physiological basis. This means that overall cultural practices should be adapted to special needs and requirements of the crops grown and to the character of the soil type. Consequently, in order to deepen the sphere of plant roots, the conditions of cultivation must be improved both in the surface soil and in the subsoil.

To this end we elaborated a method for the reclamation of sandy soils (Egerszegi, 1958, 1959). This method essentially consists in: 1/deep loosening of the sand, and 2/placing one or more at least 1 cm thick layers of manure or compost rich in colloids, into the soil, proceeding upward from underneath at depths between 38 and 75 cm.

This method of sand reclamation exerts a fundamental influence on the physiological processes of plant life by means of deep cultivation and by creating high nutrient concentration. By deep cultivation the root mass becomes redistributed to the depth of the loosened layer (Dvoracsek and Dvoracsek, 1961). As the moisture capacity of the inserted layer differs from that of the sand medium high concentration of water and nutrients is brought about within a narrow space for intensive development of the physiologically active root system. In the subsoil which usually contains more moisture than the upper layers right from the outset the water and nutrient supply thus becomes continuous even when nutrients in the surface soil are no more available to plants, due to the lack of moisture in dry spells. The water stored in deeper layers of the soil is thus economically utilized, moreover, the microbial activity intensifies with increasing depth (Müller and Rauhe, 1951).

In order to support the above statements, results of two trials are presented, obtained in 1954 and 1961, under entirely different meteorological conditions. The crop was a typical sand-plant, winter rye in the former and winter wheat, a "non-sand plant", in the latter experiment.

Both trials were conducted at the Sand Experiment Station of the Research Institute Soil Science and Agricultural Chemistry of the Hungarian

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Academy of Sciences, at Őrszentmiklós. The soil was calcareous sand, low both in nutrients and in organic matter (from 0.6 to 1.0 per cent). In 1950 and 1953, respectively, 70 tons per ha of farmyard manure were ploughed in, 25 cm deep. The same amounts of manure were placed as sheets, 60 cm deep in 1950 and 45 cm deep in 1953. The size of the plots was 200 m² with four replicates.

Monthly values of precipitation during the vegetation period are shown in table 1. In the growing season 1953—1954 there was a lack of moisture amounting to 135 mm as compared to the average of 10 years, which exerted considerable influence on plant growth and crop yields.

Table 1

Distribution of precipitation (mm) during the vegetation period

Year	Month											Sum of precipitation mm	Annual sum
	IX.	X.	XI.	XII.	I.	II.	III.	IV.	V.	VI.	VII.		
Mean of 10 years	41	33	53	54	39	35	32	46	52	59	48	492	542
1953	10	16	13	10									384
1954					34	20	34	51	44	38	87	357	547
1960	30	100	101	51									709
1961					31	28	—	65	87	48	61	602	509

To elucidate the course of plant development the increase of dry matter in the rye variety "Lovászpatonai" is shown in Figure 1. Full lines relate to the increase in dry matter of the above ground parts of the crop.

Since flowering stage (25.5.1954), the samples taken were divided into stalks, leaves and ears, respectively. Figure 1 indicates, by dotted lines, the dry weight of the aerial parts of the plants without ears. The area enclosed between the dotted and the full lines reflects the characteristic trend of ear formation.

Sudden increase in dry weight of plants in the plots ameliorated by deep-placed layers was noticed between shooting and earing (from 28.4 to 7.5). This was the period when plants intensively utilized the layer substances. In these stages of growth the plants in the check plots could hardly satisfy their needs for water, and those in the superficially manured plots only to a small extent. Though in the latter case large amounts of nutrients were available in the soil, with the drying up of the surface layer the continuous water supply of the roots extending near the surface was entirely cut off. *By contrast*, the curve representing the weight increase in the reclaimed plots runs to the end point almost without break, although the fresh weight did not increase any more after the beginning of seed set. In this case the root system utilized exactly the water reserves accumulated in the deeper layers, which were not available to the crops in plots which were supplied with nutrients only near the surface.

The effectivity of sand reclamation was unequivocally proved by daily growth rates, by phenological data and by analytical results for plant organs and seeds. This is shown in Table 2.

It appears from table 2 that rye grown in reclaimed sand exhibited larger and broader ears and higher numbers of seeds per ear. According to the morphological characters of the grain and to the baking quality grades of the flour the indices of grain and flour value similarly show the positive influence of sand reclamation.

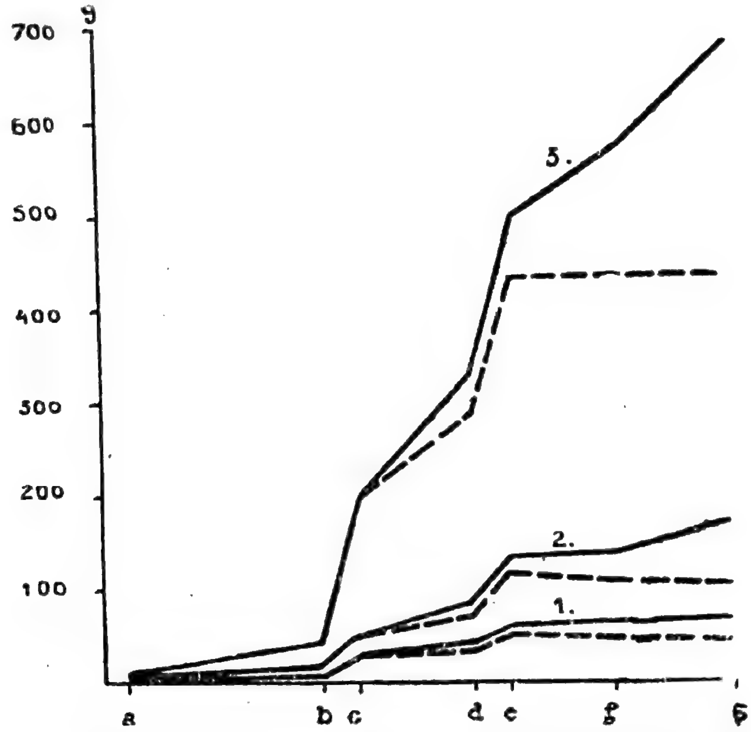

Fig. 1. Increase in dry weight of the aerial parts of rye (per 100 plants): *1* — Check, — *2* Surface-manured; *3* — Sand reclaimed with deep layers of organic matter; *a* — Full tillering stage (30.3.1954), *b* — In shooting (28.4.1954); *c* — Before earing (7.5.1954); *d* — Flowering stage (25.5.1954); *e* — Beginning of seed set (2.6.1954); *f* — Onset of waxy ripening (18.6.1964); *g* — At harvest (8.7.1954).

Table 2

Morphological characters of rye ears, yield and flour quality data

Treatment	Ear dimensions lenght cm	Ear dimensions width mm	Number of grains	Grain yield, q per ha	1000 grain weight g	Number of grains in 100 g	Laborográf Score	Laborográf Grade
1. Ploughed 25 cm deep	4.00	7.00	11	4.78	20.10	4975	25.94	B_2
2. Surface manuring	7.18	7.60	24	12.37	23.08	4333	25.98	B_2
3. Sand reclaimed by placed layers	10.26	9.00	45	25.09	23.72	4216	30.21	B_1

Note. Fertilizer applications were equal in all plots in all years.

According to histological analyses the formation of larger ear and grain yields was made possible by the increase of all types of tissue as well as by elongation. Total tissue diameter and particularly number and size of vascular bundles increased. Hereby the nutrient supply of vegetative and reproductive organs improved, finally resulting in increased weight and better quality of yield. In the reclaimed plots the yield of rye was 5.25 times as high as in the check plots and 2.59 times as high as that obtained with 25 cm deep cultivation and manuring notwithstanding the deficit of precipitations amounting to 135 mm.

Thus, by deepening the root sphere, sandy soils and even shifting sands can be adapted to the successful growing of various "nonsand crops".

This statement was confirmed by the results of a trial with the "intensive" winter wheat variety "F 481", conducted in 1961. In one of the treatments the manure was introduced into the surface layer of the soil, while another treatment involved deep cultivation only. In a third treatment the same amounts of manure as in the first (70 tons per ha in each case) were placed as separate continuous layers, the depths being 62 cm in 1953, 46 cm in 1957 and 38 cm in 1960 (Plot size was 250 sq.m. with four replications).

In the growing season 1960—61 there was an excess of precipitation amounting to 110 mm compared to the average of 10 years.

The distribution of precipitation was rather irregular in 1961. From 13.2. till 19.4. no rain fell at all, then a wetter period followed. At the time when small grains ripened the weather was exceedingly hot. Subsequently a dry spell ensued (7 mm rain in August, nothing in September). In spite of the abnormal weather, especially the severe drought in spring, the wheat grew well in the reclaimed sand. It displayed mesomorphic features at the same time it made poor growth and retarded development in the other plots. Here the lower leaves turned yellow and dried about April 10th. The crop stand exhibited typical signs of insufficient moisture. More vigurous growth set on subsequently to rains. Nutritional disturbancies manifested themselves mainly by smaller ears, increased numer of sterile spikelets and xeromorphic character of the plants.

To evaluate nutrient efficiency and crop yield, as well as water utilization efficiency, data are presented in tables 3 and 4, respectively.

It is evident from table 3 that there are no significant yield differences between treatments 1 and 2., viz. shallow and deep cultivation. The same is true for the N, P, K, and Ca content of the grain. According to experience gained so far, deep cultivation secures high yields only in combination with increased amounts of fertilizers applied. In the case of normal sandy soils the deep cultivation alone has positive effects lasting but one year or two. Yield levels are correlated with an enhanced root growth as a consequence of the deep cultivation, provided that the development and functions of a physiologically active root system are warranted. Favourable and lasting changes in the physical properties of the soil are induced by altering conditions which hinder phsiological processes, i.e. through the shattering of hard pans cemented by lime or iron compounds (e.g. Ortsand) present in the subsoil (Egerszegi, 1963).

Table 3

Wheat crop yields an nutrient content of grain

Treatment	Grain Straw yield	q per ha	Grain : straw ratio	N	P	K	Ca
				Nutrient content of the grain g/m² on the air-dry basis			
1. Ploughed 25 cm deep	12.90	26.41	2.05	2.12	0.88	0.65	1.18
2. Deep tillage	13.50	27.60	2.04	2.17	0.96	0.68	1.18
3. Shallow incorporation of manure	17.54	30.40	1.73	2.85	1.20	0.87	1.53
4. Sand reclaimed with deep layers of organic matter	27.08	42.94	1.59	4.65	1.97	1.33	2.38
L.S.D., 5 per cent	2.44	9.32		0.34	0.22	0.14	0.28

N o t e.] Fertilizer applications were equal in all plots in all years.

In the above wheat experiment the straw to grain ratio was most favourable in the reclaimed plots. Compared to shallow manuring there was an increase in grain yield amounting to 10 q per ha.

Figures for N, P, K and Ca content of air-dry grains (g per m²) correspondend to yield levels.

According to moisture determinations at harvesting time (table 4) the most efficient water utilization has been found in the reclaimed plots. The surface manuring plots had from 5.5 to 6.2 per cent by weight water in the 30 to 60 cm horizon, in contrast to 2.9—3.4 per cent in the sand depth of the reclaimed sand. This surplus of utilized water, also contributed to the increase in yield (the original minimum water capacity of the sand was about 10 per cent). The moisture capacity of the inserted sheet layer of organic matter, differring from that of the sand, locally increased the stored amounts of available water. Its nutrient reserves were, at the same time, important sources of nutrition for the plants during several years. The per-

Table 4

Soil moisture at harvesting time (22. 6.1961)

Sampling depth, cm	1. Ploughed 25 cm deep	2. Deep tillage	3. Shallow incorporation of manure	4. Sand reclaimed with deep layers of organic matter
	Soil moisture, per cent by weight			
0—10	3.6	3.7	3.4	2.1
10—20	5.5	5.7	5.7	3.5
20—30	5.9	6.3	5.9	3.3
30—40	6.2	6.8	5.6	2.9
40—50	6.3	6.7	5.8	3.2
50—60	6.0	6.5	6.2	3.4

manence of the layer is the consequence of its undisturbed state, as microbial decomposition and mineralization rate of the organic matter is reduced (Egerszegi, 1959).

Besides the non-specific wheat also other crops, e.g. alfalfa and maize, were successfully grown on mobile sand. In an experiment conducted on a large scale (at Kutas, 1963), where the soil was a clay-illuviated sand, the superficially manured maize suffered from severe drought and yielded only 19.52 corn per ha. At the same time the yield amounted to 41.5 q per ha in the reclaimed plots.

It should be noticed that the deep cultivation of sand and deep placement of nutrients — by deep ploughing if necessary — combined with careful putting into practice of all proper cultural practices, is of importance for crop yields not only in dry but also in irrigated farming, because it greatly increases irrigation efficiency

Under climate conditions prevailing in Hungary, practical application of the sand reclamation method is spreading, to increase yields, not only in agriculture but also in other branches of plant production, especially in vineyard and fruit growing.

The correctness of the underlying principle has also been verified by positive results obtained in other countries.

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SUMMARY

Taking into consideration plant physiology principles, a method was elaborated in order to obtain a lasting improvement of sandy soils, by creating a deep root zone. The essence of this method is that one or more layers consisting of manure or compost rich in colloids are placed into the soil at depths from 38 to 75 cm proceeding upward from underneath; the thickness of each layer must be at least 1 cm.

Deep cultivation and deep placement of nutrients are thus important yield increasing factors, not only in dry-farming but also under conditions of irrigation farming.

Out of our long-term experiments the result of two of our experiments are presented; these have been conducted withrye and wheat, respectively, in years with rather differing weather conditions.

With cultivation and manuring to a depth of 25 cm the yield of rye and wheat amounted to 12.37 and 17.54 q per ha, respectively. Corresponding data in the reclaimed plots were 25.09 and 27.08 q per ha, respectively.

RÉSUMÉ

En tenant compte des principes de la physiologie végétale, nous avons élaboré un procédé pour l'établissement d'une zone de nutrition profonde sur des sols sablonneux en vue de leur amélioration durable. Son principe est que, par un labour profond, nous établissons dans le profile sableux entre 38 à 75 cm, en procédant de bas en haut, une ou plusieurs couches de fumier organique ou de compost riche en colloïdes, chaque couche devant avoir au moins 1 cm d'épaisseur.

Le labour profond et le placement des principes nutritifs en profondeur sont ainsi des facteurs importants d'augmentation de la récolte non seulement dans l'agriculture sèche, mais aussi dans l'agriculture irriguée.

Nous présentons ici des expériences faites avec du seigle et du blé, dans deux années à conditions météorologiques différentes, prises parmi nos expériences de plusieurs années.

Dans le cas du labour et de la fumure à 25 cm, le seigle a donné 12,37 q/ha de grains et le blé 17,54 q. Sur le sable amélioré, le rendement en grains a été de 25,09 q/ha pour le seigle et de 27,08 q/ha pour le blé.

ZUSAMMENFASSUNG

Auf pflanzenphysiologischen Grundlagen wurde ein Verfahren zur dauernden Verbesserung von Sandböden durch Schaffung tiefer Wurzelkronen ausgearbeitet. Das Wesentliche dieser Methode besteht im Unterbringen einer oder mehrerer Schichten von Stallmist oder von kolloidreichem Kompost im Sandprofil, in Tiefen von 38 bis 75 cm, von unten nach oben fortschreitend; (falls mehrere Schichten gelegt werden) eine jede Schicht soll zumindest 1 cm dick sein.

Tiefkultur und tiefes Einbringen von Nährstoffen sind wichtige ertragssteigernde Faktoren, nicht nur in der Trockenkultur, sondern auch bei künstlicher Bewässerung.

Von unseren langjährigen Versuchen, werden hier zwei besprochen; diese wurden in Jahren von recht unterschiedlicher Witterung mit Roggen, bezw. Weizen angelegt.

Bei Flachkultur bis zu 25 cm und oberflächennaher Düngung beliefen sich die Körnererträge auf 12,37 dz Roggen und 17,54 dz Weizen pro ha. Auf den meliorierten Parzellen wurden 25,09 dz Roggen bzw. 27.08 dz Weizen pro ha geerntet.

DISCUSSION

D. KIRKHAM (U.S.A.). Many farmers on mechanized farms do not keep cattle but have much straw. Can wheat straw, rye straw, or cornstover mixed with commercial fertilizer be used for this sand reclamation process? Can green manure be used?

S. EGERSZEGI. We have conducted many experiments in this topic. The results were very good, but only with cornstover, mixed with commercial fertilizers.

The deep placed green manure, and deep ploughed green manure — respectively — in our conditions in Hungary were also efficient.

J. M. GOSNELL (South Africa). How are the layers of manure placed at depth on a commercial scale?

S. EGERSZEGI. One of the possible ways of the practical application of this method is to pour the material of the layer from a trailer following the ploughing tractor right at the bottom of the deep, clean and open furrow. This work can be completely machanized. In the case of half mechanization (which does not require special machinery) the layer material poured into the furrow must be stretched by manual work into a layer.

The other method consists of the even distribution of the improving substance over the surface of the soil. This material will be mixed 8—10 cm deep into the top-soil. The upper layer is then ploughed under together with the improving substance. This is done with a plough

suited for deep cultivation. The improving substance should get evenly to the bottom of the deep furrow. The depth of the layer is in horticultural plants about 40 cm, in field crops between 40 and 60 cm, in woody plants (grapes, fruit, etc.) 65—90 cm or more.

Cl. R. GÄTKE (Deutsche Demokratische Republik). Liegen Untersuchungsergebnisse vor, aus denen ersichtlich ist, ob in den Schichten, die horizontal in den Boden mit organischer Substanz eingebracht wurden, ein Reduktionspotential gebildet wird? Für die unteren Schichten wäre dies möglich.

S. EGERSZEGI. Auf den Pseudogley-Sandböden hatten wir einen schwachen Reduktionseffekt erzielt, und auch noch dann, wenn das Grundwasser ganz nahe — 60—80 cm — an der Oberfläche liegt. So wie so ist dieser Effekt in normalen Sandböden nicht erkennbar.

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MÖGLICHKEITEN DER GEFÜGEVERBESSERUNG PSEUDOVERGLEYTER BODENHORIZONTE DURCH EINE KOMBINIERTE TIEFLOCKERUNG UND TIEFKALKUNG

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I. EINLEITUNG

Neben den Hydromeliorationen mit einer direkten Einflussnahme auf die Bodenfeuchteverhältnisse gewinnen diejenigen Massnahmen, die sich mit der Aufbesserung bodenmässig bedingter Leistungsbegrenzungen unterschiedlicher Ausprägung und Ursache beschäftigen, in zunehmenden Masse an Bedeutung. Als spezielle Bodenmeliorationen sind sie auf die nachhaltige Beeinflussung so wichtiger Bodenfruchtbarkeitsfaktoren, wie den Bodenchemismus, die Textur-, Humus- und Gefügeverhältnisse ausgerichetet und wirken sich je nach dem Verbesserungsgrad direkt und indirekt auf die meist im Vordergrund stehende Bodenfeuchtedynamik aus (Olbertz, 1960). Die recht bedeutenden Leistungsbegrenzungen, die z.B. die grosse Gruppe der sogenannten tagwasservernässten Böden aufweist, sind in diesem Sinne auf bodenmässig bedingte Ursachen zurückzuführen. Sie sind daher bei aller Unterschiedlichkeit ihrer Entstehung und Wirkungsweise nur durch eine Aufbesserung der sie hervorrufenden Faktoren nachhaltig zu beseitigen, was die fast immer ungenügende Wirkung einseitig ausgerichteter Hydromeliorationen bestätigt (Teipel, 1956). Ein Vorgehen, bei dem ausgehend von den spezifischen Begrenzungsursachen einer genau definierten Standorts- oder Bodenform, die jeweils in Frage kommenden Verbesserungsmöglichkeiten abgeleitet, in entsprechenden Versuchen überprüft und zu standortsspezifischen Verfahrenskombinationen zusammengefasst werden, trägt den Erfordernissen nach einer rationellen und wirkungsstarken Meliorationstätigkeit ebenso Rechnung wie der Erschliessung neuer Einsatzbereiche. Es hat die in der Praxis noch vorherrschende empirische Arbeitsrichtung in immer stärkerem Masse abzulösen.

II. AUFGABENSTELLUNG, AUSGANGSVERHÄLTNISSE UND VERFAHRENSGRUNDLAGEN

Die recht bedeutenden Leistungsbegrenzungen, die durch die profilbedingten Störungen des Wasser- und Lufthaushaltes auf verschiedenen Pseudogley-Standorten im Bereich der Thüringer Verwitterungsböden auftreten,

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gaben in Verbindung mit dem weitgehenden Versagen der Dränung als traditionellen Meliorationsverfahren dazu Veranlassung, Feld- und Laboruntersuchungen zur Erfassung der Dynamik dieser Böden durchzuführen und hierauf aufbauend verschiedene, standortsspezifisch in Frage kommende Meliorationsverfahren einer näheren Überprüfung zu unterziehen. Es wurden zwei Standorte ausgewählt, die sich in der Hauptsache durch das geologische Ausgangssubstrat in Form des Tonschiefers bzw. des Mittleren Buntsandsteins sowie in der Mächtigkeit der beiden Standorte gemeinsamen jungpleistozänen Deckschichtenfolge unterscheiden und als Hauptbegrenzungsfaktor einen dichtgelagerten Staukörper in einer Tiefenlage von 0,35—0,90 m bzw. 1,10 m aufweisen. Seine Entstehung basiert in der Anlage, nach Untersuchungen von Schilling und Wiefel (1962), auf fossilen Bodenbildungsvorgängen, die Weiterentwicklung trägt jedoch eindeutig rezenten Charakter. Die sehr geringe Wasserdurchlässigkeit des Staukörpers führt in der darüberliegenden Stauzone vorwiegend im Frühjahr zu Vernässungserscheinungen und zur Wachstumsverzögerung durch Luftmangel. Der witterungsbedingt unterschiedlich ausgeprägten Nassphase schliesst sich bei Jahresniederschlägen von 600 mm infolge der begrenzten Wasseraufnahme nur eine kurze Feuchtphase an, der dann die recht ausgedehnte Trockenphase meist schnell folgt und die bedeutende Wechselfeuchtigkeit erklärt.

Leitgedanken für die Auswahl entsprechender Meliorationsvarianten war die Gefügeverbesserung des bodenphysikalisch und - chemisch ungünstig beschaffenen Staukörpers, die Erhöhung der Wasserdurchlässigkeit (Zakosek, 1960; Schönberg und Lorenz, 1962) und dementsprechende Vergrösserung des Speicherraumes sowie der Verzicht auf Abführung des wertvollen Niederschlagswassers von der Fläche.

Unter Hinweis auf die ausführliche Darlegung der geologischen, sowie der physikalischen und chemischen Verhältnisse der Bodenprofile durch Gora (1964) zeigt die Abbildung 1 den für beide Versuchsstandorte typischen Profilaufbau. Sie lässt die Ausdehnung des Stauhorizontes deutlich erkennen und deutet die ungünstigen Gefügeverhältnisse, die als Polyeder-, Prismen- oder plattiges Gefüge vorliegen, als Ursache für die schlechten physikalischen Eigenschaften des Bodens mit Folgewirkungen auf das Bodenleben und die laufenden chemischen Prozesse an. Die spezifische Darstellung des Dreiphasensystems in Abbildung 2 kennzeichnet den Verdichtungshorizont und die durch ihn verursachten Begrenzungen in der vertikalen sowie horizontalen Wasserbewegung, das Auftreten akuten Luftmangels bei voller Wassersättigung sowie seine Begrenzung von 0,35— auf 0,80 m bezw. 1,10 m besonders deutlich.

In bodenchemischer Hinsicht sind die ungünstigen Reaktionsverhältnisse des Staukörpers mit pH-Werten von 3,8—4,2 sowie der ausserordentlich niedrige Basensättigungsgrad mit V-Werten von 4—6% zu erwähnen. Die Sorptionskapazität dürfte bei dem Vorwiegen der Illitgruppe durch die

mangelhafte Versorgung mit basisch wirksamen Substanzen ebenfalls als reduziert anzusehen sein. Es muss ferner angenommen werden, dass die starke Verarmung an basischen Kationen die Aggregatbildungsprozesse nur selten über das Primärstadium hinauskommen liess und als die Hauptursache für

Abb. 1. Pseudogley-Profil des Versuchsstandortes (Tonschieferverwitterung).

die Ausbildung der ungünstigen und instabilen Gefügeformen anzusehen ist. Es ergab sich hieraus die Veranlassung, bei der Auswahl bzw. Entwicklung neuer Meliorationsmöglichkeiten die Verbesserung der chemischen Kenngrössen in den Vordergrund zu stellen.

Diese kurz genannten Ausgangsgrundlagen führten zur Entwicklung eines Tieflockerungs- und Kalkungsgerätes, welches den Stauhorizont in seiner Gesamtheit mechanisch aufzulockern und eine möglichst gleichmässige Einbringung von Kalk sowie gegebenfalls auch anderer chemischer bzw. physikochemisch wirksamer Stoffe zu sichern vermag. Neben der technischen Erprobung wurde das Hauptaugenmerk auf die boden- und ertragsmässigen Auswirkungen und ihre Nachhaltigkeit gelegt, die durch Eindringen von Krumenmaterial in den gelockerten Staukörper sowie zusätzliche Massnahmen zu seiner verstärkten Durchwurzelung mit Hilfe einer mineralischen Tiefdüngung möglichst unterstützt werden sollten.

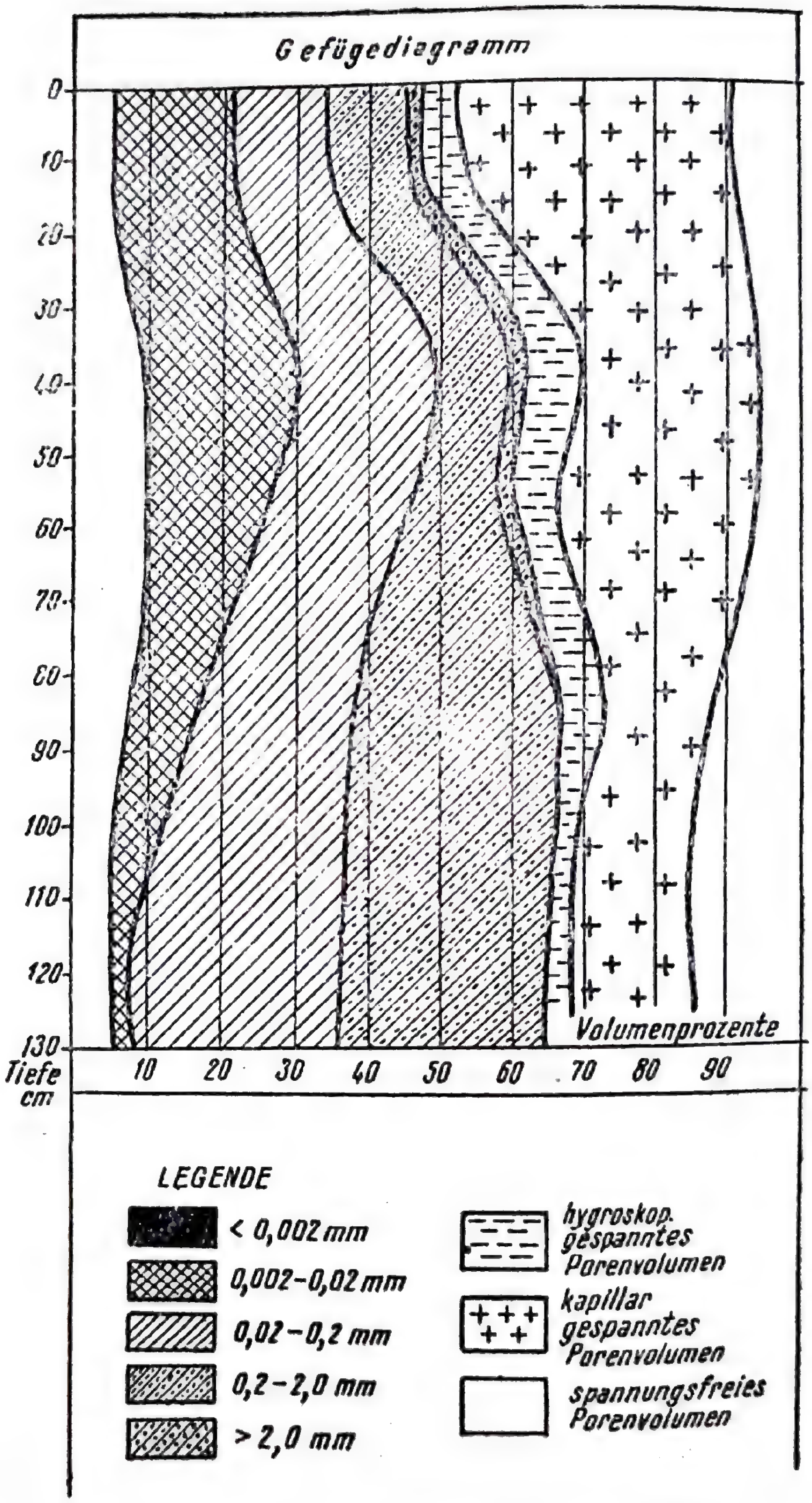

Abb. 2. Bodenprofildiagramm (Dreiphasensystem).

Die Abbildung 3 zeigt das von uns entwickelte Gerät. Wichtigste Arbeitswerkzeuge sind das Schwert mit beiderseits je dreiseitlich angebrachten, keilförmig gestalteten Lockerungsscharen, deren Arbeitsbreite nach jeder

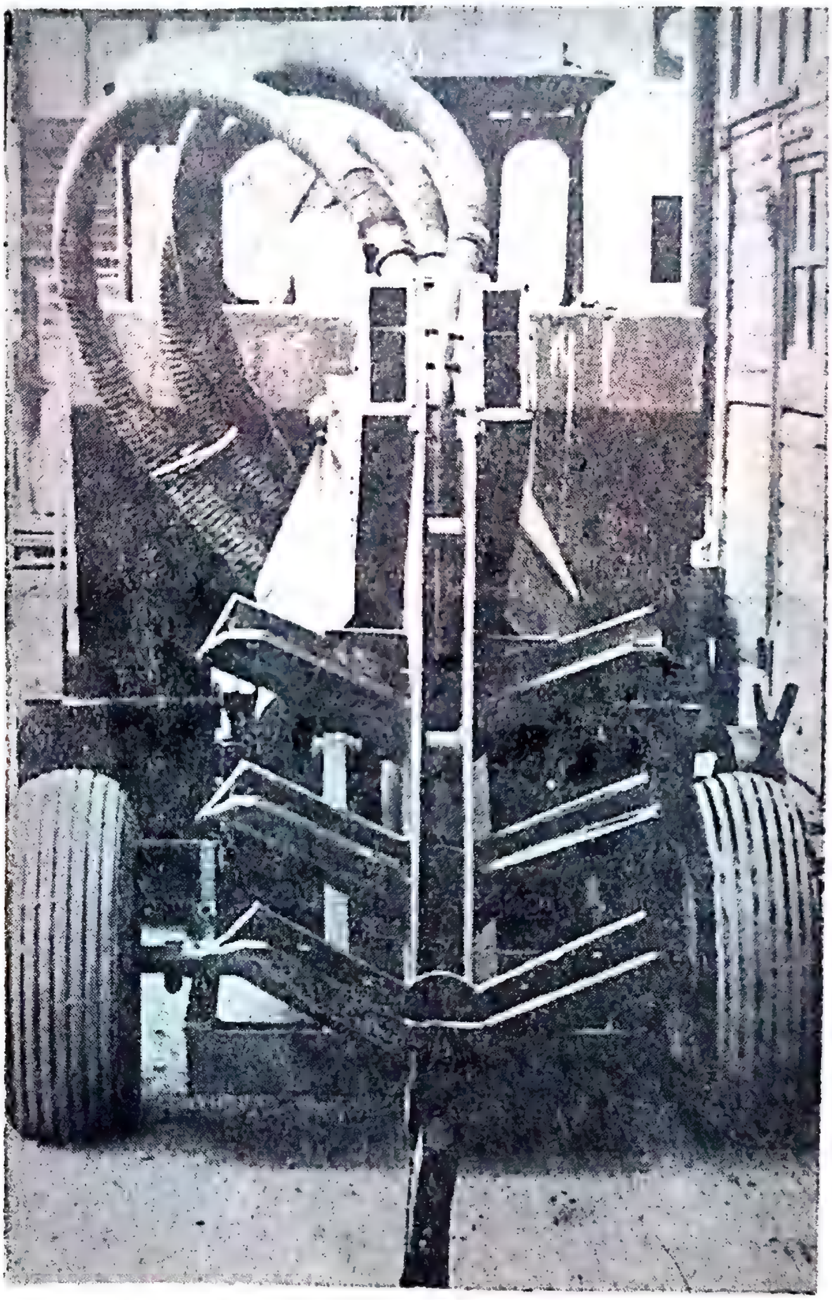

Abb. 3. Kombiniertes Tieflockerungs- und Kalkungsgerät.

Seite 320 mm beträgt. Ferner die Einrichtungen zur Tiefeinbringung des Kalkes bzw. anderer Nährstoffe und Bodenverbesserungsmittel mit den Bauteilen Vorratsbehälter, Rührwerk, Förderschnecke sowie einem Druckge-

bläse und den Kalkzuführungsleitungen. Letztere werden vom Schwert aufgenommen und treten an der Hinterseite der Lockerungschare aus. Die Verteilung erfolgt also mit Druckluft durch die Leitungsrohre in den gelockerten Bodenkörper. Eine Dosiereinrichtung erlaubt die Einbringung der verschiedensten Mengen bis zu 400 dt/ha. Bei einem Abstand der einzelnen Arbeitsgänge von 0,80 m ist die Lockerungswirkung bei nicht zu hohem Bodenfeuchtegehalt sehr gut und die Kalkverteilung in den drei Tiefen ebenfalls durchaus befriedigend. Ein Einsatz in der zweiten Jahreshälfte zur Erzielung einer günstigen Lockerungswirkung ist zu empfehlen. Bei Arbeitstiefen über 0,60 m Tiefe wird ein Kettenschlepper von 100 PS benutzt, der über eine Zapfwelle und Hydraulik verfügen muss. Einzelheiten über die technische Ausbildung des Gerätes sowie die Arbeitsweise und - qualität sind einer gesonderten Veröffentlichung zu entnehmen (Gora und Schwarz, 1964).

IV. DIE AUSWIRKUNG DES VERFAHRENS AUF DEN BODEN UND DAS PFLANZENWACHSTUM

Zur Überprüfung der Eignung des Verfahrens unter den genannten Bedingungen wurden 1961 folgende Versuchsvarianten angelegt:

1) Tieflockerung;
2) Tieflockerung und Oberflächenkalkung (30 dt/ha);
3) Tieflockerung und Tiefkalkung (210 dt/ha);
4) Tieflockerung und Tiefkalkung (420 dt/ha);
5) Tieflockerung und Tiefkalkung (210 dt/ha) + Tiefdüngung mit P_2O_5 und N;
6) Kombinierte Maulwurfsdränung mit Saugerabständen von 2,5 + + 3,5 m. Jede der genannten Varianten erhielt eine wirtschaftliche Mineraldüngung von jährlich 90 kg P_2O_5, 160 kg K_2O und 80 kg N bzw. eine Meliorationsdüngung mit 160 kg P_2O_5, 320 kg K_2O und 160 kg pro ha. Die nachfolgend angegebenen Ergebnisse beziehen sich auf den Pseudogley-Standort auf Tonschiefer mit einem A-Btg-Bt/C—D Profil (Gora, 1964), der sich in Dauergrünlandnutzung als Mähweide befindet.

Die jeweils im Frühjahr und Herbst vorgenommenen Profilaufgrabungen lasssen als Folge der Melioration ein durchgehend aufgelockertes Gefüge erkennen, das auf den Varianten mit kombinierter Tieflockerung-und -kalkung nach zweijähriger Dauer in noch annähernd vollem Umfange vorhanden ist. Die Abbildung 4 gibt über spezifischen Verfahrenswirkungen in bodenphysikalischer Hinsicht nach zweijähriger Versuchsdauer Auskunft. Die Gegenüberstellung der beiden wichtigsten Varianten (nnbehandelt sowie Tieflockerung und -kalkung) lässt die günstige Verschiebung des Dreiphasensystems zugunsten eines erhöhten Porenraumes und einer Verbesserung der Wasser- und Luftführung erkennen. Beachtenswert für den anzustrebenden Ausgleich der extremen Wechselfeuchtigkeit erscheint ferner besonders die Zunahme des Wasserspeicherungsvermögens im gesamten Bodenraum. Als weitere Beurteilungsgrundlage werden in der Abbildung 5 die Aus-

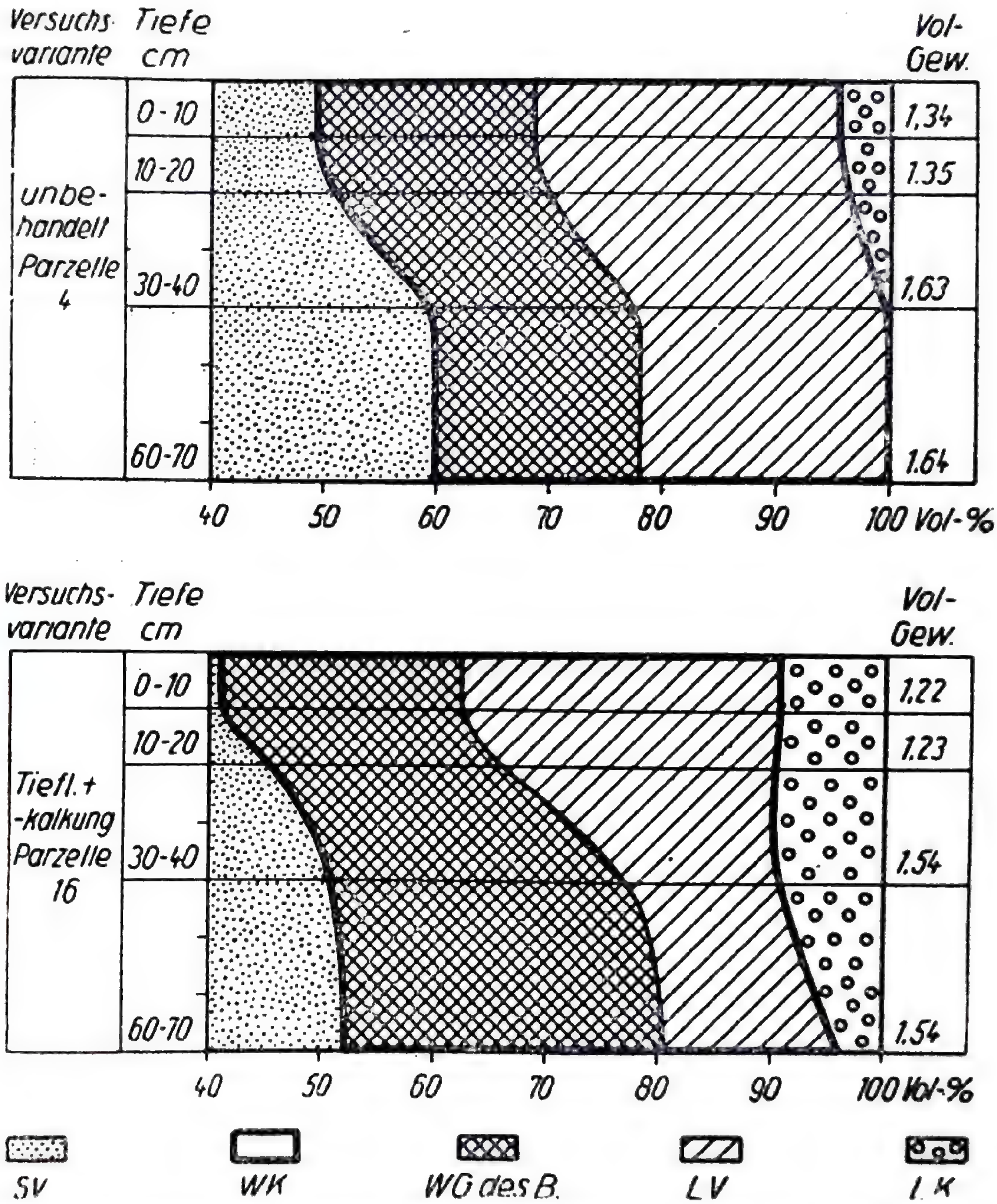

Abb. 4. Physikalische Kenngrössen des unbehandelten und tiefgelockert und -gekalkten Profils. Standort Wöhlsdorf, Herbst 1962.

wirkungen des Verfahrens auf die Erhöhung der Wasserdurchlässigkeit angegeben. Sie beziehen sich wiederum im Interesse der Übersichtlichkeit auf drei Hauptvarianten und lassen den günstigen Effekt des kombinierten Verfahrens an Hand der bedeutend erhöhten Durchlässigkeitswerte im Verdichtungshorizont erkennen.

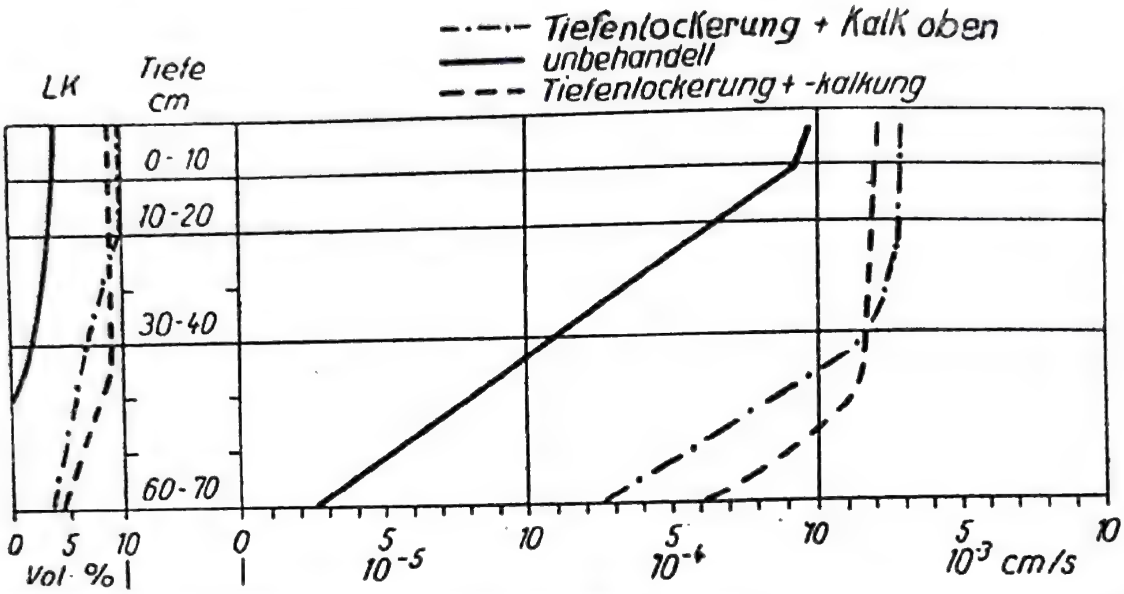

Abb. 5. Durchlässigkeit des unbehandelten und meliorativ veränderten Bodenprofils.

In bodenchemischer Hinsicht zeigen die Untersuchungen, die sich auf die Erfassung des pH-Wertes, der hydrolytischen Azidität, des CaO-Gehaltes, des T-, S- und V-Wertes sowie der organischen Substanz in den verschiedenen Tiefen erstrecken, als Folge des meliorativen Eingriffes ebenfalls eine bedeutende Veränderung. So hat sich u.a. der pH-Wert durch die starke Tiefkalkung von 4 g Kalk je kg Boden auf den Neutralpunkt erhöht. Die Basensättigung stieg im Staukörper von 10 auf 75⁰/₀ an. Ferner zeichnen sich positive Auswirkungen im Hinblick auf den Gehalt an organischer Substanz durch Einmischung von Krumenmaterial in den Unterboden und die wesentlich erhöhte Durchwurzelung sowie im gewissen Umfang bezüglich der vorwiegend von der Illitgruppe bestimmten Sorptionskapazität ab.

Im Vergleich zu diesen günstigen Veränderungen sind die durch die Verfahrensvarianten Tieflockerung und Oberflächenkalkung sowie besonders durch die alleinige Tieflockerung in den zu meliorierenden Bodenhorizonten erzielten Auswirkungen nur gering und — besonders im letzten Fall — nicht nachhaltig. In Verbindung mit den hier ebenfalls wenig ins Gewicht fallenden Ertragsverbesserungen dürfte hieraus abgeleitet werden, dass die Verbesserung der chemischen Verhältnisse durch Primär— und Sekundärwirkungen das Haupterfordernis bei der anzustrebenden Gefügemelioration dieses Standorttypes darstellt. Die Auffassung, dass der in den Btg-Horizont eingebrachte Kalk durch die von ihm ausgehende Koagulationswirkung auch auf die Stabilisierung der durch die Lockerung erzielten physikalischen Effekte in Verbindung mit der bodenbiologischen Verbesserung, Einfluss nimmt,

erscheint hiernach gegeben, wenngleich erst langjährige Untersuchungen hierüber eindeutigen Aufschluss geben können.

Die Auswirkungen der Gefügeverbesserung auf die Bodenfeuchtedynamik werden durch die Abbildung 6 gekennzeichnet, die den Feuchtverlauf in den wich-

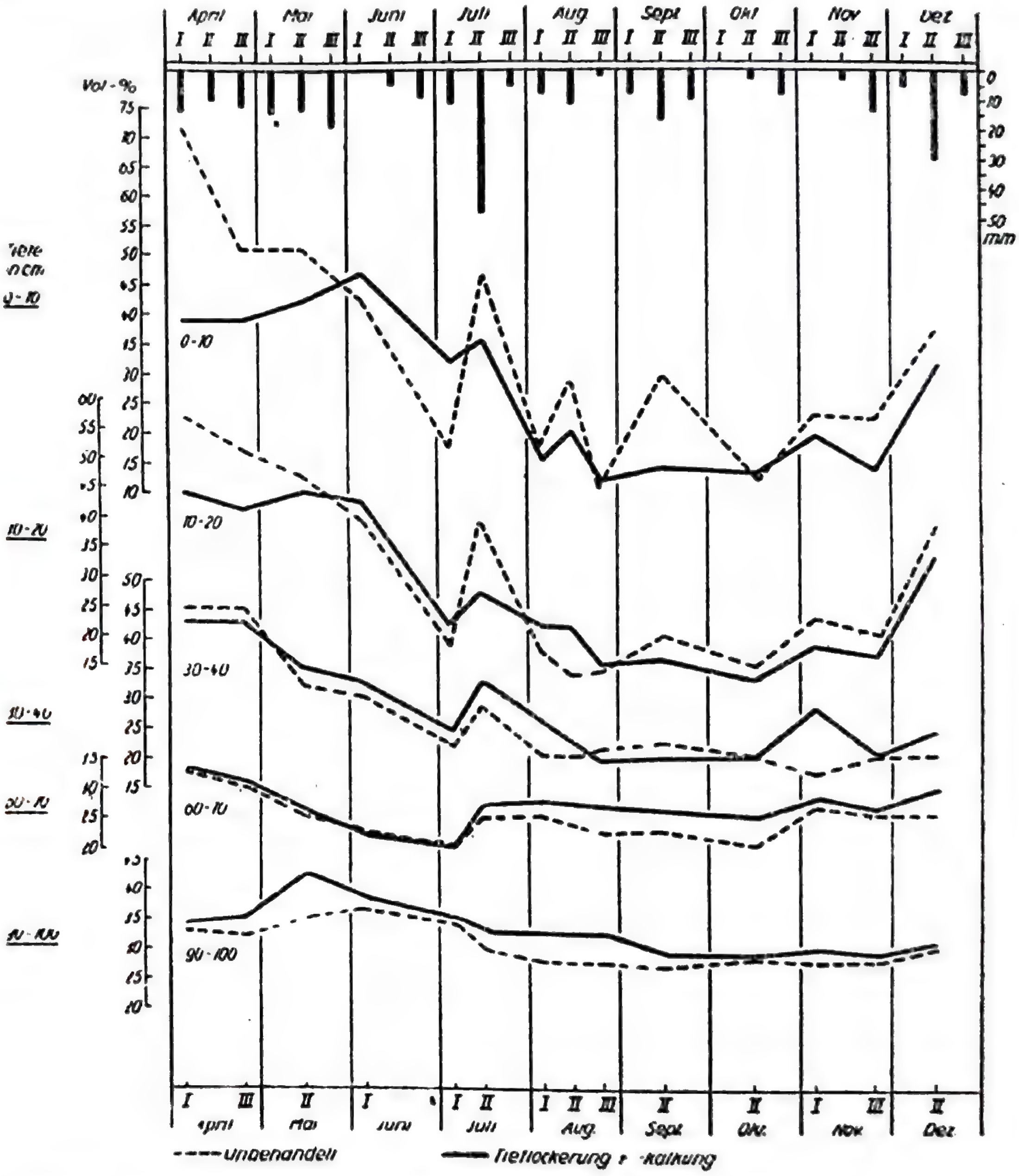

Abb. 6. Bodenfeuchtedynamik des Pseudogley-Standortes Wöhlsdorf (Tonschieferverwitterung) mit Grünlandnutzung.

tigsten Horizonten bis 1 m Tiefe in dem Zeitraum von April—Dezember widerspiegelt. Bei einem Vergleich der Tieflockerungs- und Kalkungsvariante mit der unbehandelten fällt insgesamt der ausgeglichenere Kurvenverlauf als Folge des meliorativen Eingriffes auf. Im Sinne des Meliorationszieles ist der Wegfall der Nassphase in der über dem ursprünglichen Staukörper liegenden

Bodenschicht sowie das höhere Wasserdargebot in den tieferen Bodenschichten während der Hauptwachstumsmonate von besonderer Bedeutung. Beide günstigen Effekte sind auf die erhöhte Durchlässigkeit und Wasseraufnahmebereitschaft des Btg-Horizontes zurückzuführen und lassen auch in dieser Hinsicht erste Schlussfolgerungen über die Eignung des Verfahrens

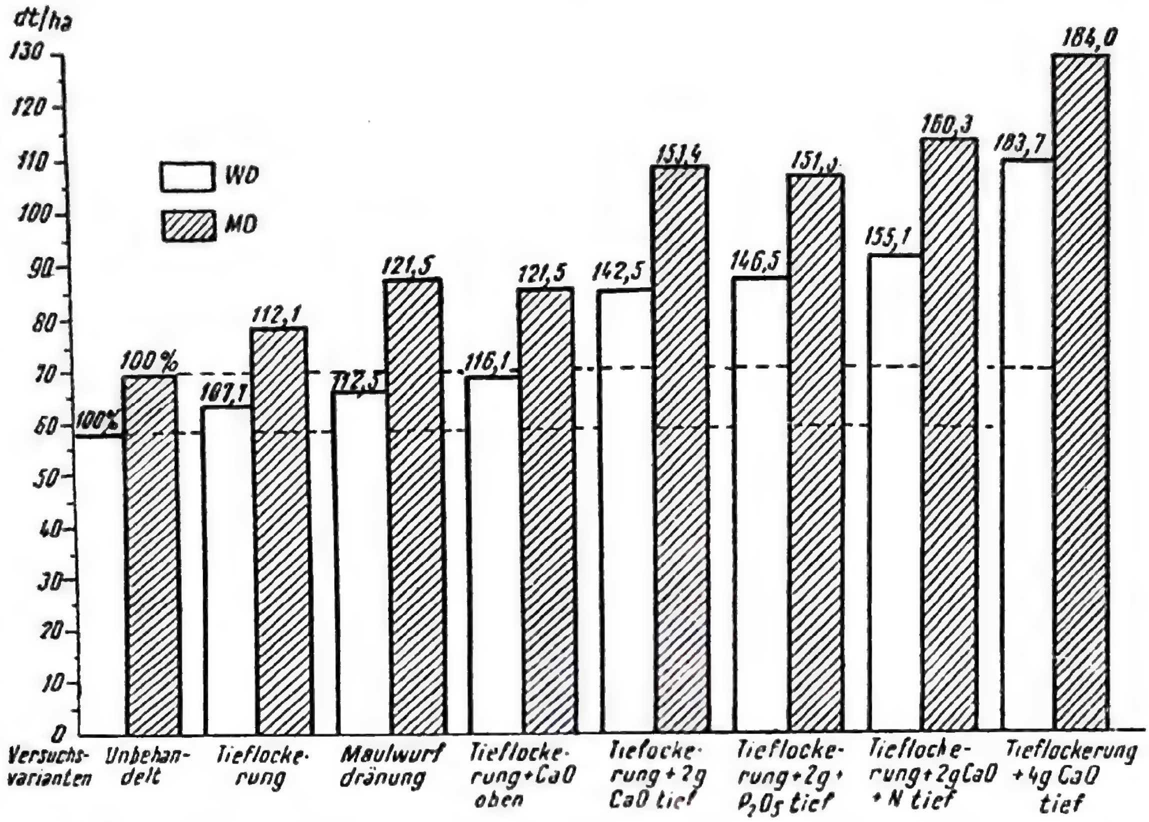

Abb. 7. Einfluss der verschiedenen Versuchsvarianten auf den Grünland-Trockenmasseertrag.

gegenüber der Dränung unter diesen speziellen Bedingungen zu. Sie erklären überdies auch die geringere Wirksamkeit der Maulwurfsdränvariante, die bei der hier notwendigen flachen Lage wertvolles Niederschlagswasser abführt, in ihrer strukturverbessernden Wirkung auf die direkte Umgebung der Erdgänge begrenzt ist und die bodenchemischen Ursachen der zeitweiligen Vernässung auch in Verbindung mit einer Oberflächenkalkung nur unvollkommen beseitigt.

Eine weitere wichtige Beweisführung über die komplexe Meliorationswirkung liefern die Ertragsergebnisse. Die beiden folgenden Abbildungen geben hierüber näheren Aufschluss. Abbildung 7 zeigt die Auswirkung verschiedener Verfahrensvarianten der Tieflockerung mit Oberflächen- und Tiefdüngung, die eine deutliche Überlegenheit der Tieflockerung mit der starken Tiefkalkung von 4 g je kg Boden und den nur geringen Effekt der mechanischen Auflockerung in Verbindung mit der Oberflächenkalkung erkennen lassen. Die zur Anregung des Wurzelwachstums in die Tiefe zusätzlich vorgenommene N-Tiefdüngung macht sich bei der Bildung des oberirdischen

Ertrags nur wenig bemerkbar, während Wurzelauswaschungen einen deutlichen und sicher bodenbiologisch nicht unwichtigen Effekt dieser Variante zeigen. Entsprechend der ungünstigen Nährstoffversorgung des Standortes wirkt die oberflächige Meliorationsdüngung mit NPK im Vergleich zur normalen Wirtschaftsdüngung deutlich und lässt die Bedeutung einer optimalen

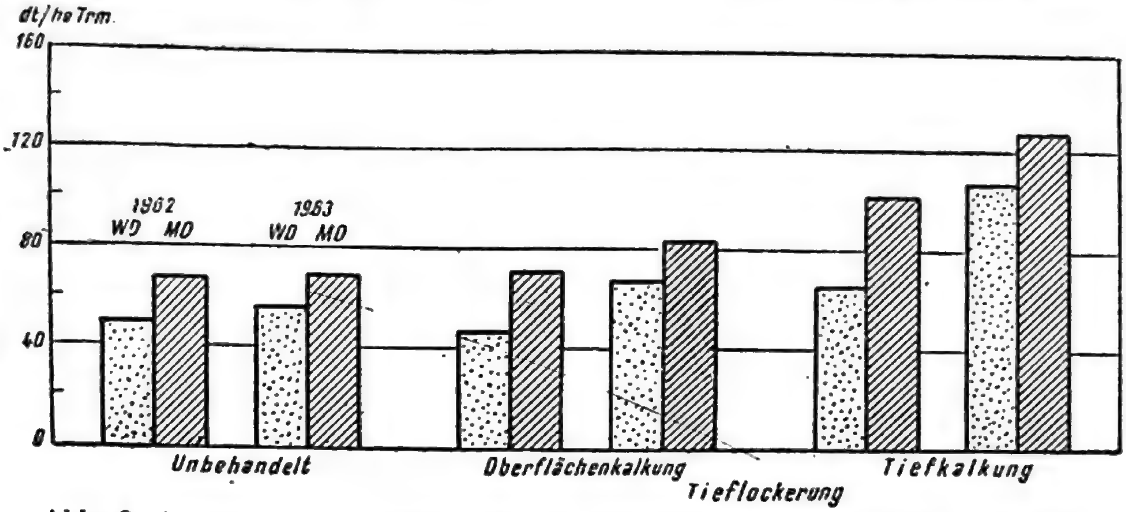

Abb. 8. Auswirkungen der Tieflockerung und-kalkung auf den Grünlandertrag.

Mineraldüngung ebenfalls in besonderem Licht erscheinen, wobei ihr Effekt durch die Gefügeverbesserung ebenfalls sichtbar erhöht wird. Die Abbildung 8 zeigt abschliessend einen Vergleich der Variante Unbehandelt, Tieflockerung und Oberflächenkalkung sowie Tieflockerung und Tiefkalkung, wiederum jeweils mit Wirtschafts-und Meliorationsdüngung. Aus ihr wird vor allem die Zunahme der Absoluterträge der komplexen Unterbodengefügeverbesserung mit zunehmender Wirkungsdauer deutlich, die einen ersten Hinweis über die Nachhaltigkeit liefert und weiter verfolgt werden muss.

Trotz des Vorbehaltes der erst kurzfristigen Ergebnisse und der Auswertung weiterer Beurteilungsfaktoren, wie z.B. der Porengrössenverteilung, der mikrobiologischen Veränderungen sowie der Aggregatstabilität, sind die erzielten Ergebnisse so ermutigend, dass wir schlussfolgernd folgende Verfahrenskonzeption als aussichtsreich betrachten: Einmal die Anwendung der kombinierten Tieflockerung und -kalkung als alleiniges Gefügemeliorationsverfahren für Pseudogleytypen mit einer entsprechenden Ausbildung des Staukörpers ohne absoluten Wasserüberschuss sowie eine kombinierte Anwendung mit der Dränung bei einem niederschlagsmässig oder hydrologisch bedingt vorhandenen, tatsächlichen Überangebot von Wasser.

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ZUSAMMENFASSUNG

Ausgehend von dem Erfordernis des Meliorationswesens, die meliorativen Eingriffe in verstärktem Umfange auf die Beseitigung der primären Ursachen der standörtlichen Leistungsbegrenzungen auszurichten, wird unter Hinweis auf bereits erfolgte Veröffentlichungen bezüglich der bodenkundlichen Verhältnisse der ausgewählten Pseudogleystandorte über die Verfahrensgrundlagen und -technik einer kombinierten Tieflockerung und -kalkung zur Gefügemelioration des ertragsbegrenzenden Btg-Horizontes berichtet und erste Ergebnisse über die Auswirkungen des Verfahrens auf einige physikalische und chemische Kenngrössen des Bodens sowie die Ertragsbildung mitgeteilt. Die Untersuchungen lassen eine positive Veränderung des Dreiphasensystems durch Erhöhung des Porenvolumens, der Wasserspeicherung sowie Wasser- und Luftführung erkennen. Der Bodenfeuchteverlauf kann unter weitgehendem Wegfall der Nassphase in der Oberbodenschicht und einer erwünschten Wasseranreicherung im Unterboden ausgeglichener gestaltet werden. Der Einfluss auf die Ertragsbildung ist bei einer Erhöhung auf annähernd den doppelten Ausgangsertrag bedeutend und lässt innerhalb des bisherigen Untersuchungszeitraumes eine zunehmende Tendenz erkennen. Die Untersuchungen werden zur Ermittlung der Nachhaltigkeit fortgesetzt.

SUMMARY

After dealing with the requirements of ameliorations, and after stating that large-scale ameliorating practices are to be directed towards the elimination of the primary causes which limit site productivity, results are reported with reference to studies already published concerning soil conditions of the selected surface-water gleyed sites upon basic practices and technics in connection with the combined deep loosening and deep liming, aiming at the structural amelioration of the yield limiting Btg-horizon; first results of these practices upon some physical and chemical characters of the soil as well as upon yields are reported. The researches show a positive modification of the three phase system: increased pore volume, water retention and water-and air permeability. The moistening process may be more balanced by a large elimination of the wet phase from the A-horizon and by a desired water storage in the subsoil. The influence on yield is significant according to the present research interval, as it is doubled and demonstrates further increasing trends. The researches are going on in order to ascertain the duration of effectiveness.

RÉSUMÉ

En partant des exigences des principes des améliorations en vue d'acheminer d'une proportion plus importante les interventions vers l'élimination des causes primaires des limitations de la productivité des stations, on rapporte — en mentionnant les publications déjà parues sur les conditions pédologiques des stations aux sols à pseudogley, publications sur les procédés

de base et la technique d'un ameublissement profond et d'un chaulage combinés afin d'améliorer la structure de l'horizon BT_g, limitant la production — les premiers résultats obtenus concernant les effets du procédé sur quelques caractères physiques et chimiques du sol, ainsi que sur la productivité. Les recherches permettent d'établir un changement positif du système à trois phases par l'augmentation du volume des pores, l'accumulation de l'eau, ainsi que la circulation de l'eau et de l'air. Le processus d'humectation du sol peut être réalisé d'une facon plus équilibré par l'élimination dans une large mesure de la phase humide de la couche supérieure du sol et par un enrichissement correspondant de l'eau dans le sous-sol, assez souhaitable. L'influence sur la productivité, approximativement le double de la productivité initiale, est importante et laisse entrevoir dans l'intervalle des recherches poursuivies jusqu'à présent, une tendance ascendante. On continue les recherches afin d'établir les effets de durée de ce procédé.

DISCUSSION

K. VAN DER MEER (Niederlande). Hat der durch Sie angewendete Apparat, auch eine gewisse Wirkung als Maulwurfsdränung?

K. SCHWARZ. Die Wirkung des Gerätes entspricht in bestimmtem Umfang derjenigen des Maulwurfsdränspfluges.

Sie ist jedoch hinsichtlich der Auflockerung, die hier physikalisch im Vordergrunde steht, intensiver. Eine Maulwurfsdränvariante ist in dem Feldversuch mit vorhanden. Sie zeigt nur eine geringe Wirkung.

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INFLUENCE OF PLOUGHING DEPTH AND OF MINERAL FERTILIZER DOSES ON SOME PHYSICAL AND CHEMICAL PROPERTIES ON PARAPODZOL AND BROWN LESSIVÉ SOILS ON LOESS

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In recent years field crop farming in Croatia — especially in its continental part — has been intensified, in which a decisive role has been played by tractor in soil tillage, mineral fertilizears, and both high-yielding varieties of wheat and maize hybrids.

In connection with the aforementioned it was of scientific interest to establish how various ploughing dephts and large amounts of mineral fertilizer influence some physical and chemical properties of the soil. For this purpose we chose two soils, a parapodzol in the north-west and a brown lessivé soil on loess substratum in the east, as representatives of the most important field corp regions of Croatia.

The parapodzol of Bozjakovina locality belongs to a region of diluvial leached-out sediments, of flattened-out mesoelevations with the proces of surface-watar gleyformation and a compactly formed B_1g_2 horizon. In the supper layer the soil is clayey-loam; deeper it is loamy-clay. The climate of this region is continental, humid.

The brown lessivé on loess substratum was investigated in two localities: one in an anthropogenized locality at Nuštar, and another more intensely moistened at Rokovci. Both of them are situated in eastern Slavonia. As regards texture, these soils are in the upper layers clayey-loam, and in the deeper ones loamyclays.

The climate of the region is subhumid with a strongerin fluence of eastern continental climate; in fact a region of forest-steppe integrating the forest zone.

1. LITERATURE ON THE PROBLEM

So far, very little work has been done regarding the physical and chemical changes in the soil under the influence of ploughing and of mineral fertilizing on parapodzols and brown lessivé soils on loess in Yugoslavia.

Popović (1959) carried out investigations on the parapodzol of northern Bosnia concerning the aspect of tillage and fertilization influence on the phy-

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sical and chemical properties of the soil, especially in respect to the available aluminium.

Bašović (1963) worked on the parapodzol in northern Bosnia, on soils with shallow and very compact B horizon of a plateau. Studies on ploughing (to 45 cm depth), mineral and organic fertilizations and liming influences, especially in connection with available aluminium, were carried out.

Mihalić, Škorić and Racz (1963) studied some physical and chemical changes produced by the influence of ploughing depth and subsoiling on the parapodzol of north-western Croatia, locality of Vrbovec.

2. METHODS OF EXPERIMENTAL WORK

In our investigations the ploughing depths were as follows: 20 cm (standard), 30-, 40-, 50-, and 60 cm. The mineral fertilizers were applied in three doses: low (300 kg/ha-N 70 kg, P_2O_5 130 kg, K_2O 100 kg), medium (490 kg/ha—N 130 kg, P_2O_5 200 kg, K_2O 160 kg) and high dose (680 kg/ha N 190 kg, P_2O_5 270 kg and K_2O 220 kg). The fertilizers were calcium ammonium nitrate (20.5 per cent N), superphosphate (16—18 per cent P_2O_5), muriate of potash (40 per cent K_2O) and mixed fertiliter 2:4:40. The following maize hybrids were cultivated: Iowa 4417, Wisconsin 641 AA and Wisconsin 355.

The physical properties we studied were the absolute water-holding capacity, the air capacity, the pore volume, the stability of microstructural aggregates in distilled water, the apparent specific gravity. Among the chemical properties we studied humus (after Lichterfeld), pH in water and KCl, available aluminium (after Sokolov) (only on parapodzol), as well as the available phosphorus and potassium (Al-method).

The initial conditions regarding the physical and chemical properties were determined in summer on stubble fields prior to the execution of the tillage and fertilization treatments, and again after winter, before sowing of maize, after harvesting the maize, and under wheat for still another year.

The yields were measured on the experimental plots (maize being taken as the main index) with the purpose of relating their amount to the changes brought about by ploughing and fertilization.

3. RESULTS OF INVESTIGATIONS

On account of restricted space we are presenting on the investigated soils only the most important data from the very large analytical material:

Parapodzol (Božjakovina). The structure of macroaggregate was before the treatment, to 30 cm slightly stable, and up to 60 cm unstable. Neither ploughing nor fertilization improved the stability of the macrostructural aggregates but a tendency to deterioration was noticed.

— The ploughing strongly increased the *pore volume* especially in the categories of 60 cm depth from the initial 47.80 per cent up to 55.05 per cent in the surface layer (which has been maintained for two years).

— *The absolute water-holding capacity* generally falls down slightly after ploughing and then in the following year it increases rapidly, even over the intial values, increasing regularly with the increasing ploughing depths (30 cm. 44.60 per cent, 50 cm 45.70 per cent, and 60 cm 48.15 per cent.

— *The apparent specific gravity* increases at the beginning regularly with the depth of the soil, then there occurs an inversion, and it decreases in the surface layer with the increasing ploughing depth . At 30 cm ploughing depth it amounted to 1.30, at 40 cm, to 1.36, at 50 cm to 1.28, and at 60 cm to 1.19. In the following year the values increased but they remained below the initial level.

— The amount of *available aluminium* is in general low, and up to 30 cm it is below 1 mg, while up to 60 cm, it increases to 5.64 mg. Consequently, by augmenting the ploughing depth the amount of available aluminium increases. Even the maximum dose of fertilizer did not decrease the amount of available aluminium. However, it did not have any bad effect on the yields.

— *The humus* up to 30 cm varies from 1.61 to 2.67 and at greater depths it rapidly drops below 1 per cent. Therefore, with increasing ploughing depth the humus content of the surface layer decreases though in an irregular manner. On manured and unmanured plots, after maize crop, the humus content increased.

— The soil is *acid*, and by augmenting the ploughing depth the acidity in the upper layer increases. At 60 cm ploughing depth and with the maximum fertilizer dose it increases up to 4.15 in KCl. But these plots gave high yields of maize grains (96.24 qts).

— *The available phosphorus* up to 30 cm averages 11 mg, while at greater depths it is considerably lower (3.3 mg). With the increasing ploughing depth the available phosphorus in the upper layer decreases, while fertilization slightly increases the amount of available phosphorus only in the layer up to 30 cm.

— As regards the amount of *available potassium*, the soil up to 30 cm is in the class III from the point of view of supply (5.2 to 9.4 mg) By increasing ploughing depth one decreases slightly the available potassium, while fertilization produces a reduced effect on the increase in potassium content, and this only in the layer up to 30 cm.

The brown lessivé soil on loess (localities of Nuštar and Rokovci). On the markedly anthropogenized soil at Nuštar the initial *stability the soil macroaggregates* was found to become from unstable to slightly stable, while in more strongly moistened soil at Rokovci it was completely unstable. In both localities, after treatment, a deterioration of the structure condition is conspicous.

— As regards the *pore volume*, up to 30 cm depth both soils are porous, while at 60 cm depth they are slightly porous (42.55 per cent). Ploughing up to 30 cm slightly changes porosity, but with a deep ploughing it increases considerably (Nuštar 50.18 percent, and Rokovci 53.29 percent. Such

a state lasts in Nuštar for a period of one year. At Rokovci the porosity decreases at 50 and 60 cm ploughing depths.

— *The air capacity* at Nuštar, up to 30 cm depths, was at the very beginning 8.01—10.52 per cent and at 60 cm depth 6.19 per cent; at Rokovci 9.48 per cent and at greater depths 5 per cent (more compact layer). Ploughing, especially to 50—60 cm. depth, has considerably increased the aeration and this was more profound at Rokovci (20.53 per cent and 21.60 per cent). However, in the course of the maize growing season a drop, occurs especially on the more strongly moistened soil at Rokovci.

— *The water-holding capacity* was medium at the very beginning in both localities up to 60 cm depths (35—39 per cent). After ploughing, at Nuštar, the state in general does not change, but at Rokovci a decrease, occurs which is greater at 60 cm depth. However, as the time elapses the values gradually increase even beyond the initial state (up to 44.89 per cent) when ploughing to 60-cm at Nuštar).

— *The apparent specific gravity* was in both soils, up to 30 cm depth, between 1.4 to 1.5 , while it increased at Nuštar at 60 cm depth. By ploughing the apparent specific gravity decreases in general and regularly with increased depth, so that at Rokovci it falls at 60 cm ploughing depth to 1.28 and then it increases in the courses of time (Nuštar).

— As regards the *humus content* both soils belong to poor humous soils (1—3 per cent). No greater changes occur.in the content humus at all ploughing depths. After the maize harvest a small increase was determined — mostly at mediume and high fertilizer doses (Rokovici).

— With regard to the *soil reaction* at Nuštar, up to 60 cm depths the soil is from weakly acid to weakly basic, and at Rokovci from weakly acid to neutral. With the increase in ploughing depth and of fertilizer doses the pH increases. After the maize harvest a slow drop was observed at Nuštar, while at Rokovci the pH was in general unchanged.

— With respect to the *available phosphorus*, both soils up to 30 cm depth are in class I and II from the point of view of supply. However at Nuštar the soil up to 30 cm depth remaines in class II, and at Rokovci it falls into class III. By ploughing to the greatest depths, at Nuštar the available phosphorus content decreases a little, while at Rokovci it exhibits variations. Ploughings to 60 cm depth with and without fertilizing resulted in more available phosphorus than by plouguing to smaller depths. Fertilization to 30 cm depth increases at the very beginning the amount of available phosphorus, while in the second year a drop occurs.

— As to the *available potassium*, both soils up to 60 cm depth are in class II of supply (10—20 mg). With the increase of ploughing depth the potassium content practically does not decrease, while at Nuštar fertilization in the layer up to 30 cm slightly increases the available potassium. At Rokovci with the increase of ploughing depth the available potassium slightly decreases, while with fertilization it increases slightly. In the course of time a slight fall was recorded.

4. DISCUSSION AND CONCLUSIONS

The previous investigations of parapodzols in Croatia (Mihalić, Skorić, Racz) and in northern Bosnia (Popović and Bašović) have shown that this group of soils is of a low productive capacity primarily because of the bad water-air relationship and the scarceness of plant nutrients. The conclusion was that by the application of deep tillage and mineral fertilizers one does not improve all the elements of fertility, but that by a radical improvement of the soil water and air regimes, its productive capacity instantly and considerably increases, this being expressed by better yields of field crops (maize, wheat etc).

Popović (1959) and Basović (1963) were concerned with a parapodzol with a greater amount of aluminium (up to 41 mg in the layer at 60 cm) and by the application of mineral fertilizers they achieved a considerable blocking of the mobile aluminium, and good yields of field crops were obtained.

All investigations on the parapodzol — including our own — confirm that on ploughing from 20 to 60 cm depths and applying the main fertilizers (300—600 kg of pure nitrogen, phosphorus and potassium nutrients per ha), the soil remained poor in available nutrients, acid and with a poor structure, but after a physical improvement and a mineral fertilization its productive capacity rose considerably, a fact confirmed by the high yields of 105.72 qts/ha of maize grains obtained at Božjakovina.

In general, we can say for both investigated soil groups that tillage (ploughing) changes much more the physical and chemical properties of the soil than fertilization, and that ploughing changes much some physical properties (pore volume and air capacity). We consider that from these facts one should draw — besides a slight and even negative influence on soil fertility — the following explanation of the considerably increased productivity: better conditions were achieved for crop nutrition and as a consequence higher yields were obtained.

With regard to the investigated properties of the soil we can draw the following conclusions:

a) Regarding the *physical properties* of parapodzol and brown lessive soils on loess, the *pore volume* and the *air capacity* increase most intensely under the influence of ploughing (especially of deep ploughing) and that this is more pronounced on parapodzol.

By increassing ploughing depths the soil *apparent specific gravity* decreases, then, in the course of time, it increases, remaining within the investigated period below its initial values.

The absolute water-holding capacity decreases following ploughing, especially following deeper ploughing, then subsequently it increases, but up to the end of the investigation it remained below the initial level.

b) Regarding the chemical properties of the investigated soils we established that the total *available aluminium* content on the parapodzol at Božjakovina is in general small, though it somewhat increases with depth (at 60 cm 5.64 mg). Therefore, with increasing ploughing depth the mobile

aluminium content also increases in the upper layer. Fertilization did not reduce its content, but aluminium did not limit the yields at all.

By increasing the ploughing depth in both soil groups the *humus content* decreased, and then it increased linearly on manured and on unmanured plots.

On the parapodzol soil the *acidity* increases with increasing ploughing depth, while on the brown lessivé soils on loess it decreases up to the transition to the neutral zone (involving carbonate loess). In the course of time the pH decreased gradually.

Available phosphorus is lacking on parapodzol. By increasing the ploughing depth the amount of available phosphorus decreased in the upper soil layer. On brown lessivé soils on loess which are rich in phosphorus, the available phosphorus content decreased only in the layer up to 30 cm.

The investigated soils are evenly supplied as regards their depth, with *available potassium*, for which reason no ploughing category can change considerably its content in the upper layer, nor does this occur under the influence of fertilization. A certain increase of the level of available potassium was recorded mostly in the layer up to 30 cm depth.

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SUMMARY

From 1961 to 1963 the main physical and chemical properties of parapodzol and brown lessivé soils on loess, under the influence of ploughing (20—60 cm) and the standard mineral fertilizers (70—190 kg N/ha, 130—270 kg P_2O_2/ha and 100—220 kg K_20/ha) were investigated. It was established that ploughing (especially deep ploughing) changed the investigated properties much more than fertilizing.

The ploughing-primarily on the parapodzol- worsened the elements of soil fertility, but the maize yield was increased by the improvement in water-air relationship and availability of nutrients.

RÉSUMÉ

De 1961 à 1963 on a examiné les principales propriétés physiques et chimiques du parapodzol et des sols bruns lessivés sur loess en tant qu'influencés par le labour (20—60 cm) et les engrais minéraux standard (70—190 kg N/ha, 130—270 kg P_2O_2/ha et 100—220 kg K_2O/ha). Il a été établi que le labour (spécialement le labour profond) a modifié les propriétés soumises à l'examen beaucoup plus que la fertilisation. Le labour — en premier lieu chez le parapodzol — a nuit aux éléments de fertilité, mais le rendement de la récolte de maïs a augmenté du fait de l'amélioration survenue dans le rapport eau-air et de l'accessibilité des éléments nutritifs

ZUSAMMENFASSUNG

Von 1961 bis 1963 wurden die hauptsächlichsten physikalischen und chemischen Eigenschaften von Parapodsolböden und Para-Braunerden auf den Einfluss des Pflügens (20—60 cm) und der Standard-Mineraldünger (70—90 kg N/ha, 130—270 kg P_2O_2/ha, und 100—220 K_2O/ha) untersucht. Es wurde festgestellt, dass das Pflügen (insbesondere das Tiefpflügen in weit grösserem Masse die untersuchten Eigenschaften veränderte, als dies die Düngung hervorrief.

Das Ackern — in erster Reihe beim Parapodsol — schadet den Elementen der Bodenfruchtbarkeit, der Maiserntеertrag jedoch stieg dank der eingetretenen Verbesserung im Wasser-Luft-Verhältnis und in der Nährstoff-Verfügbarkeit.

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BEEINFLUSSUNG DER KOHLENSTOFFDYNAMIK DURCH TIEFE BEARBEITUNG LEICHTER BÖDEN

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Angeregt durch Hinweise in der älteren deutschen Literatur und durch die neueren Arbeiten von Egerszegi (1953), Mossolow (1954), Tjurin (1953) u.a. wurden vor nunmehr 10 Jahren in unserem Institut umfangreiche Untersuchungen zur Prüfung der Auswirkungen einer tiefen Pflugfurche auf die Fruchtbarkeit verschiedener Böden begonnen. Sie führten zur Entwicklung einer Methode des meliorativen Tiefpflügens grundwasserferner Sandböden. Diese beeinhaltet eine einmalige tiefe Bearbeitung auf etwa doppelte Krumenstärke (40—45 cm). Dabei wird mit einem besonders hierfür entwickelten Pflug die obere Hälfte des humosen *A*-Horizontes zusammen mit organischen Düngungsstoffen tief eingebracht und der übrige Bodenbalken seitlich versetzt, so dass ein Teil des *A*-Horizontes an der Oberfläche verbleibt. In den folgenden Jahren wird der Boden zunächst in der bisher üblichen Tiefe gepflügt und später im Abstand von einigen Jahren jeweils etwas tiefer.

Das meliorative Pflügen führt zu einer Verbesserung der physikalischen und chemischen Eigenschaften der Böden, bewirkt eine Steigerung der mikrobiellen Aktivität und der Durchwurzelungsintensität und bringt besonders in niederschlagsarmen Jahren bedeutende Mehrerträge (Rauhe und Müller, 1959; Müller und Rauhe, 1959; Rauhe, 1960, 1962; Koepke, 1960; Kunze, 1963). Die eindeutigen Erfolge haben eine schnelle Einführung dieses Verfahrens in die landwirtschaftliche Praxis bewirkt. In den Jahren 1962 und 1963 wurden bereits einige tausend Hektar grundwasserferner Sandböden in der Deutschen Demokratischen Republik meliorativ gepflügt, und es ist vorgesehen, in den nächsten Jahren etwa 200 000 ha auf diese Weise zu verbessern.

Bei der Prüfung des Einflusses einer tiefen Bearbeitung auf die Dynamik der organischen Stoffe im Boden wurde u.a. festgestellt, dass die Gesamtmenge an Kohlenstoffverbindungen je Hektar im Vergleich zur normalen Bearbeitung (20 cm tief) beträchtlich angestiegen war (Koepke, 1960; Rauhe und Koepke, 1964). Diese Feststellung wurde auf die Bildung einer

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höheren Wurzelmasse sowie verringerte Mineralisation der zugeführten organischen Stoffe nach meliorativem Pflügen und dadurch bedingtes Vermischen der humosen Ackerkrume (A-Horizont) mit humusarmem Unterboden (B-Horizont) zurückgeführt. Zur Untermauerung der zunächst in einem Versuch erzielten Resultate wurden weitere Versuche hinsichtlich der Beeinflussung der Kohlenstoffdynamik durch tieferes Pflügen unternommen.

Die vorliegende Arbeit behandelt neuere Ergebnisse einer Kohlenstoffbilanz in einem grundwasserfernen Sandboden im 8. Jahr nach Durchführung des meliorativen Tiefpflügens bei unterschiedlicher Düngung. Ferner wird auf der Grundlage von densimetrischen Fraktionierungen der organischen Bodensubstanz und von Stickstoffanalysen eine Aussage über die Qualität der organischen Stoffe angestrebt.

VERSUCHSGRUNDLAGEN

Die Versuchsanlage erfolgte 1955 auf einem grundwasserfernen Sandboden (degradierte Braunerde), der wegen seiner geringen Fruchtbarkeit seit 20 Jahren nicht mehr landwirtschaftlich genutzt worden war. Unmittelbar unter dem etwa 20 cm mächtigen A_p-Horizont steht sehr humusarmer, gebleichter Sand an, der in grösserer Tiefe von schwachen, eisenschüssigen Bändern durchzogen wird. Der Gehalt an abschlämmbaren Teilen liegt bei 5—6%. Der durchschnittliche Kohlenstoffgehalt im A_p-Horizont beträgt 0,55%. Bei Versuchsbeginn enthielt der Boden als Folge starker Azidität beträchtliche Mengen an freiem Aluminium.

Das Klima des Versuchsstandortes wird durch ein langjähriges Niederschlagsmittel von 545 mm und eine durchschnittliche Jahrestemperatur von 8,2°C gekennzeichnet.

Die Prüfung umfasste die folgenden 2 Bearbeitungs- und 3 Düngungsvarianten in einer zweifaktoriellen Blockanlage mit 4 Wiederholungen:

I. normale Bearbeitung bis zur Tiefe von 15—20 cm;

II. bei Versuchsanlage 45 cm tief gepflügt, danach wie (I):

a) ohne Stallmist;

b) normale Stallmistdüngung (3 Gaben mit insgesamt 750 dt/ha);

c) hohe Stallmistdüngung (3 Gaben mit insgesamt 1 350 dt/ha).

Alle Varianten erhielten bei Versuchsanlage 25 dt/ha $CaCO_3$. Die mineralische Düngung wurde einheitlich verabfolgt, wobei durchschnittlich 30 kg/ha N, 54 kg/ha P_2O_5 und 100 kg/ha K_2O jährlich gegeben wurden.

Die Bodenproben für die chemische Untersuchung wurden im Frühjahr 1963 entnommen. Auf den meliorativ gepflügten Parzellen geschah die Entnahme im Horizont von 20—40 cm getrennt aus dem verlagerten A-Horizont und dem humusarmen B-Horizont. Der Boden wurde an der Luft getrocknet und auf 2 mm abgesiebt. Die Kohlenstoffbestimmungen erfolgten durch nasse Verbrennung mit gravimetrischer CO_2-Bestimmung,

die Stickstoffanalysen nach Kjeldahl. Die Fraktionierung der organischen Bodensubstanz wurde in Anlehnung an einen Vorschlag von Monnier, Turc und Jeanson-Lunsinang (1962) durch Zentrifugieren in einer Bromoform-Tetrachlorkohlenstoff-Mischung von der Dichte 2,0 vorgenommen.

BESPRECHUNG DER ERGEBNISSE

Beim meliorativen Tiefpflügen wird ein Teil des humushaltigen *A*-Horizontes vergraben und dafür humusarmer Unterboden in den obersten Bodenhorizont eingemischt. Als Folge dieser Unterbodenbeimischung ist der Oberboden der meliorativ gepflügten Teilstücke zunächst deutlich heller als der in üblicher Tiefe gepflügter Parzellen. Der Farbunterschied wird jedoch schnell geringer und ist nach 6—8 Jahren nur noch schwach erkennbar.

Diese rein visuelle Feststellung wird durch die Ergebnisse der Kohlenstoffanalysen im Boden nach 8jähriger Versuchsdauer bestätigt (Tabelle 1).

Tabelle 1

Kohlenstoffgehalt im Boden in mg/100 g nach 8jähriger Versuchsdauer

Stallmistdüngung	Normal bearbeitet		Meliorativ gepflügt		
				20—45 cm	
	0—20 cm	20—45 cm	0—20 cm	verlagerte Krume	Unterboden
Ohne	499	74	397	412	49
Normale Gaben	558	53	445	443	59
Hohe Gaben	562	72	483	433	61
Ausgangsgehalt	535	43	(289)*		

* Aus dem Mischungsverhältnis errechnet.

Bei der üblichen Bearbeitung bis zur Tiefe von 15—20 cm hatte sich der Kohlenstoffgehalt im Oberboden im Vergleich zum Ausgangswert verringert, wenn keine organische Düngung verabfolgt wurde. Bei Stallmistdüngung war ein leichter Anstieg zu verzeichnen.

Nach meliorativem Pflügen war in der Schicht von 0—20 cm in allen Varianten eine erhebliche Anreicherung von organischen Kohlenstoffverbindungen gegeben. Im Boden der Parzellen ohne Stallmistdüngung betrug die Zunahme rund 100 mg C/100 g Boden. Das ist eine erstaunlich hohe Menge. Von Schmalfuss (1960) wurden allerdings in einem Versuch mit humusarmem Lössunterboden noch höhere Humusakkumulationsraten nachgewiesen.

Die Stallmistdüngung bewirkte einen weiteren deutlichen Anstieg des Kohlenstoffgehaltes im Boden. Auch die Höhe der Stallmistgaben spiegelt sich in den Werten wider.

In dem in den Unterboden verlagerten Teil des ursprünglichen A_p-Horizontes hatte der Kohlenstoffgehalt abgenommen. Vermutlich ist die Mineralisation der bei Versuchsbeginn im Oberboden enthaltenen leicht zersetzbaren organischen Stoffe auch nach der Verlagerung ungehemmt vor sich gegangen, während die in dieser Tiefe gebildeten Wurzelmassen für einen Ersatz nicht ausreichten.

Zwecks Gewinnung einer quantitativen Vorstellung wurden die im Bodenhorizont von 0—45 cm in den einzelnen Versuchsgliedern vorhandenen Kohlenstoffmengen berechnet (Tabelle 2). Gleichzeitig wird eine Kohlenstoffbilanz dargeboten.

Tabelle 2

Kohlenstoffbilanz im Boden nach 8jähriger Versuchsdauer

Variante	C im Boden 0—45 cm t/ha	C-Anreicherung t/ha	Durch Stallmist u. Pflanzenrückstände zugeführt t/ha	Davon im Boden verbleiben %
Anfangsmenge	18.8			
normal gepflügt				
Ohne Stallmist	19,0	0,2	5,6	4
Normale Düngung	20,0	1,2	13,1	9
Hohe Düngung	20,9	2,1	19,1	11
meliorativ gepflügt				
Ohne Stallmist	20,5	1,7	5,6	30
Normale Düngung	22,7	3,9	13,1	30
Hohe Düngung	23,9	5,1	19,1	27

Aus der Zusammenstellung wird deutlich, dass das meliorative Pflügen, insbesondere bei gleichzeitiger Stallmistdüngung, in bedeutenden Masse zur Vermehrung der organischen Bodensubstanz beigetragen hat. Während bei normaler Bearbeitung ohne Stallmistdüngung 4% und bei Stallmistdüngung rund 10% der in der Düngung und den Pflanzenrückständer enthaltenen organischen Stoffe im Boden verblieben sind, waren es bei meliorativem Pflügen rund 30%. Diese Zahlen stimmen mit früher ermittelten gut überein (s. Koepke, 1960).

Durch das meliorative Pflügen erhalten wir mithin die Möglichkeit, organische Stoffe, und damit Sorptionsträger, im Boden anzureichern. Bei normaler Bearbeitung sind diesbezügliche Bemühungen von geringem Erfolg gekrönt, wenn nicht ständig eine hohe organische Düngung gegeben wird. Auch bei tiefem Pflügen steigt der prozentuale Kohlenstoffgehalt des Bodens nicht über den für den Standort charakteristischen Humusspiegel. Durch Vertiefung des humosen A_p-Horizontes kann aber die absolute Humusmenge gesteigert werden.

Es erhebt sich hierbei die Frage, ob die möglicherweise durch Hemmung der Umsetzungen in erhöhtem Masse angereicherten organischen Stoffe hu-

musartige Verbindungen darstellen, oder ob es sich lediglich um Ansammlung unzersetzter bzw. wenig zersetzter pflanzlicher und tierischer Rückstände handelt. Zur Nachprüfung des Umsetzungsgrades wurde eine Fraktionierung der organischen Substanzen nach der Dichte vorgenommen. Dabei wurde davon ausgegangen, dass beim Zentrifugieren der Proben in einer Lösung mit der Dichte 2,0 alle wenig umgesetzten organischen Stoffe an die Oberfläche kommen, während die mit den Bodenmineralen Komplexe bildenden Humusstoffe am Boden niedergeschlagen werden. Tatsächlich schwimmen nach dem Zentrifugieren nur faserige Substanzen auf der Flüssigkeit. Das Resultat wird in der Tabelle 3 wiedergegeben.

Tabelle 3

Kohlenstoff in der leichten Fraktion der organischen Bodensubstanz in Prozent des Gesamtkohlenstoffes

Stallmistdüngung	Normal bearbeitet 0—20 cm	Meliorativ gepflügt	
		0—20 cm	verlagerte Krume
Ohne	43	33	29
Normale Gaben	45	37	30
Hohe Gaben	52	36	31

Der Anteil der leichten Fraktion am Gesamtgehalt an organischer Bodensubstanz erweist sich als sehr hoch. Rund 30—50% der organischen Stoffe waren zum Untersuchungstermin nicht oder nur unvollständig zersetzt. Die Stallmistdüngung schien die Ansammlung dieser Stofffraktion zu begünstigen. Insbesondere bei normaler Bearbeitung war der Prozentsatz der leichten Fraktion in dem mit Stallmist gedüngten Boden höher als ohne Stallmist, obgleich die letzte Mistgabe 3 Jahre zurücklag.

Eine Anreicherung nicht zersetzter Stoffe in dem meliorativ gepflügten Boden war nicht erfolgt. Im Gegenteil, im oberen Horizont von 0—20 cm lag der Anteil der leichten Fraktion am gesamten Kohlenstoff des Bodens bei normaler Bearbeitung um rund 10% höher als nach dem meliorativen Pflügen. Die Beimischung von Unterboden hatte demnach die Umsetzungsprozesse nicht gehemmt. Diese Feststellung steht im Einklang mit den Ergebnissen von Müller und Rauhe (1959), die über eine beachtliche Steigerung der Mikroorganismenzahlen im Boden als Folge der tiefen Bearbeitung berichten. Offensichtlich führen die Abbauvorgänge hier nicht bis zur vollständigen Mineralisation der organischen Stoffe, und es entstehen in grösserem Umfange Komplexe zwischen Huminstoffen, Sesquioxyden und Tonmineralen. Die Einmischung anorganischer Kolloide aus dem *B*-Horizont in den Oberboden trägt zweifellos hierzu bei.

In dem in 20—45 cm Tiefe verlagerten Krumenboden war der Anteil unzersetzter Stoffe am geringsten. Einerseits ist das dadurch bedingt, dass eine Zufuhr von organischen Substanzen in diese Tiefe nur in Form feiner Pflanzenwurzeln erfolgt, zum anderen erweist sich, dass die Umsetzungen unterhalb der bearbeiteten Schicht nicht gehemmt sind.

Der Einfluss der unterschiedlichen Behandlungen auf das C/N-Verhältnis im Boden ist aus der Tabelle 4 ersichtlich.

Tabelle 4
C/N-Verhältnis im Boden

Stallmistdüngung	Normal bearbeitet 0—20 cm	Meliorativ gepflügt 0—20 cm	Meliorativ gepflügt verlagerte Krume
Ohne	11,2	12,7	12,0
Normale Gaben	11,8	12,1	12,3
Hohe Gaben	12,0	12,2	12,2
Ausgangswert	12,4		

Bei normaler Bearbeitung hat sich das C/N-Verhältnis im Boden im Vergleich zum Ausgangswert verengt. Als Ursachen hierfür kommen Bearbeitung und Kalkung in Betracht. Auf den mit Stallmist gedüngten Varianten war das Verhältnis etwas weiter als auf den ohne Stallmistdüngung. Es besteht ein Zusammenhang mit der Anreicherung unzersetzter organischer Stoffe.

Etwas anders liegen die Werte nach meliorativem Pflügen. Im Oberboden der Teilstücke ohne Stallmist wurde ein relativ weites C/N-Verhältnis ermittelt. Hier hatte überwiegend stickstoffarmes Wurzelmaterial als Quelle für die Bildung organischer Bodensubstanzen gedient. Bei Stallmistdüngung war die Stickstoffversorgung günstiger, und es konnten demzufolge mehr stickstoffhaltige Verbindungen in die organische Substanz des Bodens eingebaut werden. Daher gleicht das C/N-Verhältnis im Boden dieser Varianten dem der entsprechenden normal bearbeiteten.

In der in den Unterboden verlagerten Krume hatte sich das C/N-Verhältnis im Verlauf der Versuchsdurchführung etwas verengt, ohne dass zwischen den Düngungsvarianten eindeutige Unterschiede vorhanden wären.

Zusammenfassend kann festgestellt werden, dass das meliorative Pflügen zu einer erheblichen Zunahme der Menge organischer Substanzen im Boden beigetragen hat. Die Qualität der angereicherten Stoffe ist dabei nicht schlechter als die im gleichen Horizont des flach bearbeiteten Bodens. Der Anteil unzersetzter Pflanzenrückstände im Boden ist nach dem meliorativen Pflügen sogar geringer als bei normaler Bearbeitungstiefe, woraus auf eine verstärkte Bildung von organomineralischen Komplexen gefolgert werden kann. Das meliorative Pflügen stellt somit eine Möglichkeit zur schnellen Steigerung der Sorptionskapazität von Sandböden dar.

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ZUSAMMENFASSUNG

In einem grundwasserfernen Sandboden (degradierte Braunerde) mit einem A_p-Horizont von etwa 20 cm Mächtigkeit, wurde die Wirkung des meliorativen Pflügens bis zur Tiefe von 45 cm auf die Dynamik der organischen Stoffe im Boden untersucht.

Nach 8jähriger Versuchsdauer konnte als Folge der Einmischung von humusarmem Unterboden aus dem *B*-Horizont in den Oberboden eine erhebliche Anreicherung von organischen Substanzen nachgewiesen werden. Von dem im Stallmist und den Pflanzenrückständen zugeführten organischen Kohlenstoff waren bei normaler Bearbeitung 4—11% zum Aufbau organischer Bodensubstanzen genutzt worden, nach meliorativem Pflügen 27—30%.

Der Anteil unzersetzter Pflanzenrückstände am Gesamtkohlenstoffgehalt war im normal bearbeiteten Boden grösser als im meliorativ gepflügten. Es wird gefolgert, dass die Einmischung von Tonmineralen und Sesquioxyden aus dem *B*-Horizont zu einer verstärkten Bildung organomineralischer Komplexe geführt hat. Im C/N-Verhältnis waren zwischen normal bearbeitetem und meliorativ gepflügtem Boden bei Stallmistdüngung keine Unterschiede vorhanden.

SUMMARY

The influence of ameliorative ploughing up to a depth 45 cm was investigated on the dynamics of organic soil substances, on a sandy soil (degraded brown soil) with a deep water table and with an A_p horizon of approximately 20 cm.

After an investigation period of 8 years an important increase in organic substances could be demonstrated as a result of the mixing-up the humus deficient subsoil (*B* horizon) with the *A* horizon soil. From the organic carbon applied as manure and plant residues, 4—11 percent were used for producing organic soil substances under normal crop conditions and 27—30 percent after ameliorative ploughing.

The part played by the non decomposed plant residues in the total carbon content was greater for the normally tilled soil than for the ameliorative ploughed one. It is deduced that the mixing-up of the clay minerals and sesquioxides of the *B* horizon induced a more significant formation of organic and mineral complexes. There were no differences in the C/N ratio between the normal tilled and amelioratively tilled soils.

RÉSUMÉ

On a examiné dans un sol sableux (sol brun dégradé) à nappe phréatique profonde et à horizon A_p d'environ 20 cm, l'effet du labourage amélioratif, jusqu'à 45 cm de profondeur, sur les substances organiques du sol.

Il a résulté-comme suite du mélange du sous-sol pauvre en humus de l'horizon B avec du sol de l'horizon A- après une période de recherche de 8 années, un enrichissement considérable en substances organiques. Dans le cas du labour normal, 4—11% du carbone organique provenant du fumier et des débris végétaux appliqués ont été utilisés pour la production de substances organiques du sol, trandis que dans le cas du labour amélioratif, cette proportion était de 27—30%.

Le taux de débris végétaux non décomposés dans la teneur totale en carbone a été plus grand dans le sol cultivé normalement que dans le sol au labour amélioratif. On en déduit que la mélange de minéraux argileux et de sesquioxydes de l'horizon B ait conduit à une formation plus intense de complexes organominéraux. En cas de fumure avec du fumier d'étable, il n'y a pas eu de différences dans le rapport C/N entre les sols cultivés normalement et ceux labourés en vue de l'amélioration.

DISCUSSION

Z. FEKETE (Ungarische Volksrepublik). Schauen die Pflanzen während einer Dürre nicht streifenartig aus? Ich habe dies bei derselben Methode bei Getreide gesehen. Die schlechteren Linien waren dort, wo die Wurzeln keine tiefere Humusschicht getroffen haben. Bei der Egerszegi Methode war alles einheitlich.

V. KOEPKE. Derartige Streifen haben wir in keinem Falle beobachten können. Im Horizont von 20—25 cm ist zwar der gegrabene Krumenboden intensiver durchwurzelt als der ursprüngliche humusarme Unterboden. Da aber die seitliche Durchwurzelung des Bodens durch die Pflanzen über die Furchenbreite, also 40 cm, hinausgeht, beeinflusst die schichtweise Lagerung von humosem und humusarmem Boden in 20—45 cm Tiefe die Entwicklung der darüber stehenden Pflanzen nicht.

F. F. R. KOENIGS (Niederlande). Wird eine Verbesserung der Wasserspeicherung oder eine des T-Wertes mit dem meliorativen Pflügen bezweckt?

V. KOEPKE. Durch die Gefügemelioration wird unmittelbar die Wasserspeicherung verbessert. Mit der Anreicherung von organischen Stoffen, die durch die tiefe Wendung erreicht wird, steigern wir aber gleichzeitig auch den T-Wert, oder, besser gesagt, die gesamte Sorptionskapazität in der bearbeiteten Tiefe.

I. MAXIM (Rumänische Volksrepublik). Wie Dr. Egerszegi und Dr. Koepke schon erwähnten, wurde in verschiedenen Ländern durch zahlreiche Feldversuche festgestellt, dass man durch tiefes Unterbringen von organischen Düngemitteln, die Fruchtbarkeit der Sandböden wesentlich heben kann.

Auf den Sandböden, die sich in der RVR am linken Ufer des Jiu-Flusses südlich der Stadt Craiova bis an die Donau erstrecken, erzielten wir durch diese Methode ebenfalls gute Erfolge.

Da aber die Meliorationspflüge für tiefes Einbringen des organischen Materials in unserem Lande zur Zeit fehlen, ist die Anwendung dieser Methode auf unseren Sandböden begrenzt.

Die Frage, die ich Herrn Dr. Koepke stelle, ist die folgende: ob der Meliorationspflug mit dem er seine Versuche ausgeführt hat, sich im Handel befindet und auf welche Weise solche Pflüge in unser Lande gebracht werden könnten.

V. KOEPKE. Der beschriebene Pflug für die Sandbodenmelioration wird unter der Bezeichnung B 185 im Volkseigenen Betrieb "Bodenbearbeitungsgeräte" in Leipzig, Deutsche Demokratische Republik, in Serie gefertigt. Er wird wahlweise als Anhänge- oder als Aufsattelpflug geliefert. Nach Auswechseln des Pflugkörpers durch einen stärker wendenden, (B 175) kann der Pflug auch zum tiefen Vollumbruch in der Forstwirtschaft oder im Obstbau benutzt werden (Plantagenpflug). Anfragen sind zu richten an: Transportmaschinen Export-Import, Deutscher Innen- und Aussenhandel, 108, Berlin Taubenstr. 11—13.

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I+VI. 23

MELIORATIVES SEGMENTPFLÜGEN EIN NEUES VERFAHREN ZUR STEIGERUNG DES PRODUKTIONSVERMÖGENS DER BÖDEN

CL.-R. GÄTKE [1]

Das Produktionsvermögen vieler ackerbaulich genutzter Böden ist bekanntlich unbefriedigend, weil deren Ackerkrumen mangelhaft entwickelt sind, und weiterhin der Übergang von der Ackerkrume zum Unterboden durch unterhalb der Ackerkrume gelegene Verdichtungszonen gemindert wird, so dass auf Grund der gegebenen klimatischen Bedingungen die Hektarerträge durch entsprechende meliorative oder ackerbauliche Massnahmen vielerorts durchaus beträchtlich gesteigert werden könnten.

Während sich Mängel in der Nährstoffversorgung durch Düngungsmassnahmen im allgemeinen relativ einfach regulieren lassen, ist die Vergrösserung und die nachhaltige Verbesserung des für den Wirkungsgrad der Nährstoffe entscheidenden, von den Pflanzenwurzeln durchzogenen Bodenraums wesentlich schwieriger und langwieriger. Daher liegt das wissenschaftliche Kernproblem des Ackerbaus auch gegenwärtig weniger in der Nährstoffversorgung der Pflanzen, sondern vielmehr in der Schaffung optimaler Wasser- und Luftverhältnisse im Boden.

Ausgehend von der vor allem im vorigen Jahrhundert bei der Vertiefung der Ackerkrume erreichten Steigerung der Hektarerträge, hat es in den letzten Jahrzehnten an empirischen Versuchen nicht gefehlt, den Pflanzenwurzeln durch noch tieferes Pflügen oder durch Unterbodenlockerung noch bessere Lebensbedingungen zu schaffen.

Die Ergebnisse derartiger Versuche, die vielfach auf nicht vergleichbaren Standorten durchgeführt wurden, liessen unterschiedliche Schlussfolgerungen zu, so dass die Meinungen über die zur Melioration des Bodengefüges erforderlichen Massnahmen mangels ausreichender bodenkundlicher Grundlagenforschungen auch heute noch wesentlich differieren.

Aus den Ergebnissen unserer bodenphysikalischen Untersuchungen über den Einfluss der Zusammensetzung der Bodensubstanz auf das Makrogefüge weitgehend natürlich gelagerter, im Bereich der Grundmoräne in Norddeutschland gelegener Ackerböden konnten wir erkennen, dass zwischen dem Gehalt des Bodens an organischer Substanz und der Aggregat-

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stabilität eine enge, exponentielle, hochsignifikante, positive Korrelation (a) und zwischen der Aggregatstabilität und dem Porenvolumen eine ebenfalls signifikante, jedoch lineare, positive Korrelation (b) besteht.

$$\text{a)}\quad r = +0{,}91\,;\; n = 477 \qquad\qquad \text{b)}\quad r = +0{,}82\,;\; n = 238$$
$$y = 8{,}11 + 8{,}76 \cdot \log x \qquad\qquad y = 23{,}94 + 17{,}7 \cdot x$$
$$\log x = -0{,}752 + 0{,}095 \cdot y \qquad\qquad x = -6{,}25 + 0{,}381 \cdot x$$

Bei speziellen Untersuchungen über den Einfluss des Reaktionszustandes im Bereich von etwa pH = 5—7, des Carbonatgehalten, der Textur und verschiedener Kulturpflanzen auf die Aggregatstabilität der Bodensubstanz zeigte sich demgegenüber eine nur geringe Wirkung dieser Faktoren, so dass die Stabilität des Bodengefüges dominierend durch den organischen Anteil in der Bodensubstanz bestimmt wird.

Gleiches gilt auch hinsichtlich des Einflusses dieser Faktoren auf das Porenvolumen des Bodens, wobei jedoch entsprechend der qualitativen Zusammensetzung und der Körnung der mineralischen Bodensubstanz die Porosität des Bodengefüges auch aus der Textur des Bodens resultiert. Dies zeigt sich vor allem bei Böden mit einem geringen Anteil an organischer Substanz ($< \sim 0{,}7\%$).

Zwischen dem Gehalt des Bodens an organischer Substanz und dessen Porosität kann auf Grund der vorstehenden Korrelationen die in der Abbildung 1 dargestellte Beziehung abgeleitet werden. Da diese vornehmlich aus Untersuchungen an Bodenarten vom anlehmigen Sand bis zum sandigen Lehm festgelegt wurde, werden durch sie die Porositätsverhältnisse stark sandiger Lehmböden gekennzeichnet. Bei den anderen Bodenarten besteht in der Tendenz der gleiche Einfluss dieser Substanz auf das Porenvolumen, wenn auch — dem Tongehalt entsprechend — dessen absolute Grösse etwas von der dargestellten Beziehung differiert.

Aus der in der Abbildung 1 dargestellten Abhängigkeit des Porenvolumens vom Gehalt des Bodens an organischer Substanz wird erhellt, dass die anzustrebende Vertiefung der Ackerkrume stets dann zu einer schnellen Steigerung der Hektarerträge führt, wenn diese innerhalb der Bodenkrume vorgenommen wird. Bei derartigen Bodenverhältnissen ist auch bei plötzlich tieferem Pflügen um 5—10 cm keine wesentliche Minderung der Gesamtporosität zu erwarten. Vorsicht scheint aber stets dann geboten, wenn durch tieferes Pflügen Boden mit einem beträchtlich geringeren Gehalt an organischer Substanz in die bisherige Ackerkrume eingebracht wird. Dies gilt aut Grund der exponentiellen Abhängigkeit des Porenvolumes vom Anteil des Bodens an organischer Substanz unter den Standortbedingungen Norddeutschlands in besonderem Masse für Ackerkrumen, deren Gehalt an dieser Substanz gering ist.

An anderer Stelle wurde von uns bereits berichtet (Gätke, 1963, 1964), dass das Auftreten und vor allem der Verdichtungsgrad der zumeist als „Pflugsohle" bezeichneten, unterhalb der Ackerkrume gelegenen Bodenzone in hervorragendem Masse gleichfalls durch den in dieser Zone vorhandenen Gehalt an organischer Substanz bestimmt wird, und bei niedrigem Gehalt diese Verdichtungszone vornehmlich aus der Verschlämmungs- und

Verdichtungsneigung des Bodens resultiert. Diese Folgerung beeinhaltet auch den Grund, warum vielfach die Unterbodenlockerung nur in einer Vegetationsperiode eine beachtenswerte Wirkung gezeigt hat. Eine nachhaltige Wirkung derartiger Massnahmen kann unter den Standortbedingungen

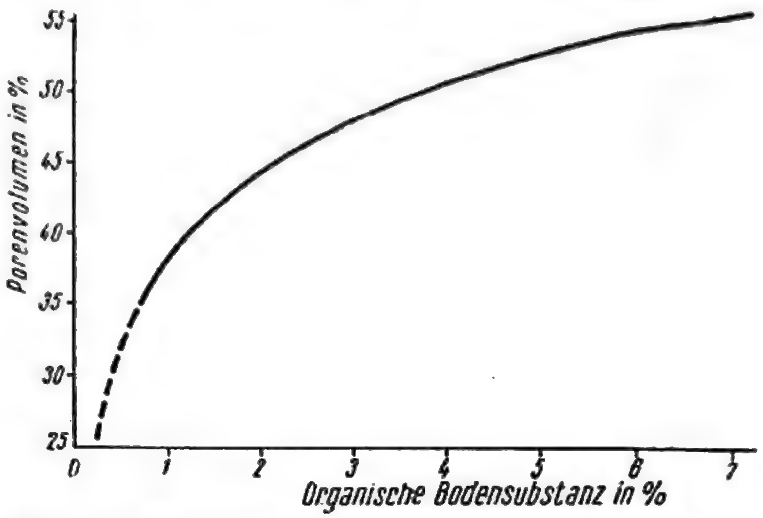

Abb. 1. Abhängigkeit des Porenvolumen vom Gehalt des Bodens an organischer Substanz.

Norddeutschlands nur auf Standorten erwartet werden, an denen das Lockerungswerkzeug innerhalb der Bodenkrume gearbeitet hat. Da das letztere aber vielfach kaum tiefer als die Ackerkrume ist, mussten beim Vorliegen derartiger Verhältnisse auf Grund der Verdichtungsneigung der gelockerten Bodensubstanz (vergl. Söhne, 1955) anhaltende Lockerungserfolge ausbleiben.

Da eine nachhaltige Minderung der Verdichtungsneigung bzw. -bereitschaft der unterhalb der Ackerkrume befindlichen Bodenzone nur nach einer entsprechenden Anreicherung mit organischer Bodensubstanz zu erwarten ist, hat die Vertiefung der Bodenkrume bis auf mindestens 45 cm Tiefe als vordringlichstes Meliorationsproblem zu gelten.

Auf der Grundlage dieser und weiterer, an anderer Stelle noch zu berichtender Forschungsergebnisse haben wir ein qualitativ neuartiges Bodenbearbeitungs- bzw. Meliorationsverfahren entwickelt (Gätke, 1958), das sogenante Segmentpflügen.

In der Abbildung 2 sind die Wirkungsweise und die zur Durchführung dieses Verfahrens erforderlichen Werkzeuge zeichnerisch dargestellt. Das meliotative Segmentpflügen beeinhaltet in der Grundkonzeption ein Zweischichtenpflug-Verfahren und ist dadurch gekennzeichnet, dass an üblichen Pflügen hinter den Pflugkörpern jeweils ein neuartiges Werkzeug, der sogenannte Segmenthobel, angebracht ist. Mit diesem Segmenthobel, der am Pflug ähnlich wie Werkzeuge zur Bodenlockerung angebracht ist und 20—25 cm tiefer als das übliche Pflugschar greifen soll, wird während des Pflügens eine etwa 7 cm breite Rinne, gewissermassen ein Segment, aus dem unterhalb der Ackerkrume gelegenen Boden geschnitten und der vom Seg-

menthobel erfasste Boden seitlich nach oben an den vom Streichblech des Pflugkörpers bereits gewendeten Krumenboden abgelegt. Im gleichen Arbeitsgang wird dann durch ein am Pflugrahmen befestigtes Messer- oder Scheibenblech die durch den Segmenthobel in den Unterboden geschnittene Rinne kontinuierlich mit Bodensubstanz aus der Ackerkrume verfüllt, so dass in jeder Pflugfurche die unterhalb der Ackerkrume befindliche, zumeist verdichtete Bodenzone im Bereich des Segments nachhaltig gelockert wird.

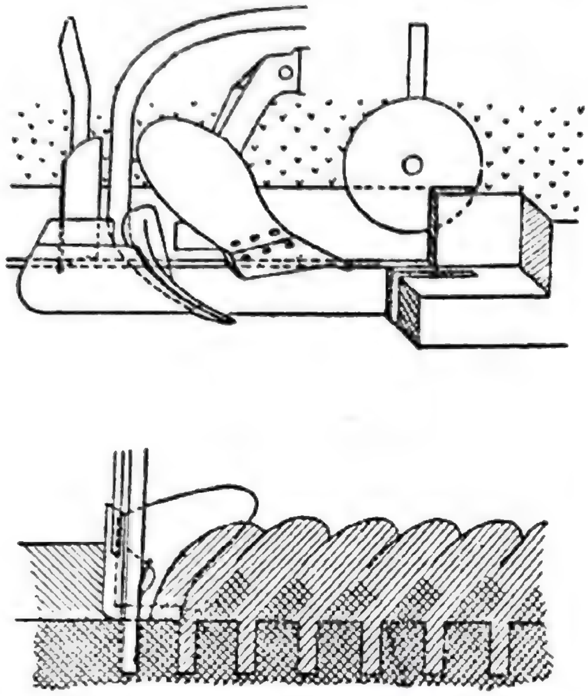

Abb. 2. Das Arbeitsprinzip des Segmentpfluges.

Mit diesem neuartigen Verfahren ist es möglich, das Gefüge des Bodens in komplexer Weise zu meliorieren, indem in einem Arbeitsgang einerseits die Ackerkrume vertieft wird, und weiterhin durch die Vertiefung der Bodenkrume auch eine wirksame Beseitigung der unterhalb der früheren Ackerkrume befindlichen Verdichtungszone erfolgt.

Gegenüber der bislang üblichen Vertiefung der Ackerkrume durch allmählich tieferes Pflügen und den verschiedenen Varianten der Unterbodenlockerung bringt das Segmentpflügen nachstehend beschriebene Vorteile.

1. Die Vertiefung der Ackerkrume bzw. der Bodenkrume kann voraussichtlich bei nahezu allen Bodenarten mit den gleichen Arbeitswerkzeugen ohne Rücksicht auf die Mächtigkeit der Bodenkrume bis in 45—50 cm Tiefe vorgenommen werden. Im Gegensatz zum tieferen Pflügen wird hierbei jedoch kein zur Verschlämmung neigender Unterboden an die Bodenoberfläche gebracht.

2. Nach einer derartigen Bodenbearbeitung steht den Pflanzenwurzeln nun auch der Unterboden offen, in den sie bislang nur mangelhaft einzudringen vermochten, wenn sich der Ackerkrume zum Unterboden hin eine Verdichtungszone anschloss.

3. Während bei tieferem Pflügen die Gefahr besteht, dass der Unterboden durch den Raddruck der Traktorenräder, die zumeist in der Furche laufen, auch in grösserer Tiefe verdichtet wird, weil derartige Massnahmen aus arbeitsorganisatorischen Gründen oftmals in den Spätherbst bei vielfach höherer Bodenfeuchtigkeit gelegt werden müssen, ist dies beim meliorativen Segmentpflügen kaum möglich.

4. Während bei den herkömmlichen Werkzeugen zur Unterbodenlockerung nur bei niedriger Bodenfeuchte befriedigende Lockerungswirkungen unterhalb der Ackerkrume zu erwarten waren, kann mit dem Segmentpflug

stets volle Wirkung erzielt werden, wenn der Boden pflugfähig ist. Somit kann dieser Pflug auch im Frühjahr mit Erfolg eingesetzt werden.

5. Durch den Segmenthobel können nach unten hin keine Schmiersohlen im Unterboden entstehen.

6. Der in der vom Segmenthobel geschaffenen Rinne lockerer gelagerte Boden ist bei späterer Bodenbearbeitung vor der Druckwirkung der Traktorenräder weitgehend geschützt, weil der Raddruck — bedingt durch die grosse Auflagefläche der Räder — durch den seitlich der Segmente befindlichen, im allgemeinen dichter gelagerten Boden aufgefangen wird.

7. Nach meliorativem Segmentpflügen ist vor allem eine positive Wirkung auf den Wasserhaushalt des Bodens zu erwarten, weil der in den bisherigen Stauhorizont eingebrachte, locker gelagerte Krumenboden eine wirksame Krumenentwässerung ermöglicht. Derartiges darf auch aus den in der Dränpraxis gewonnenen Erfahrungen abgeleitet werden, nach denen der bereits vor Jahrzehnten auf Dränrohre verstochene Krumenboden zumeist auch heute noch wesentlich lockerer als der darüber befindliche rohe Unterboden gelagert ist.

Die durch das Segmentpflügen verbesserte Krumenentwässerung, auf die übrigens Rid (1960) die positive Wirkung der bisher praktizierten Untergrundlockerung im wesentlichen zurückführt, lässt einen früheren Vegetationsbeginn im Frühjahr erwarten und mindert während der Vegetationszeit die unproduktive Verdunstung des Bodenwassers, weil bei höheren Niederschlägen das Wasser durch die sogenannten Segmente tiefer in den Boden eindringen kann und so vor der Verdunstung weitgehend geschützt ist.

Gegenüber tiefem Pflügen ist nach dem Segmentpflügen weiterhin eine bessere Wasserversorgung der Pflanzenwurzeln zu erwarten, da nach noch im einzelnen an anderer Stelle mitzuteilenden Untersuchungsergebnissen fester gelagerter Boden eine höhere Wasserkapazität besitzt. Der seitlich der Segmente befindliche, wenig gelockerte Boden kann somit als Wasserreservoir wirksam werden, an das die Pflanzenwurzeln jederzeit durch den in den Segmenten locker gelagerten Boden vordringen können.

8. Durch die positive Wirkung des Segmentpflügens auf die Wasserführung des Bodens ist auch eine beträchtliche Aktivierung zur Zeit wenig wirksamer Dränanlagen zu erwarten. Vielfach hat nämlich die geringe Wirkung alter Dränanlagen ihre Ursache nicht in einem funktionsgestörten Dränsystem, sondern darin, dass das Niederschlagswasser durch die unterhalb der Ackerkrume befindliche, als Stauhorizont wirksame Verdichtungszone nicht in den Unterboden eindringen kann. Melioratives Segmentpflügen hat deshalb auch als eine bedeutsame Folgemassnahme bei neuen Dränprojekten zu gelten. Unter Umständen, dies bedarf selbsverständlich eingehender Untersuchungen, könnten hierdurch sogar die Dränabstände vergrössert werden.

9. Da nach meliorativem Segmentpflügen eine bessere Krumenentwässerung zu erwarten ist, müsste mit diesem Verfahren auch die Anfälligkeit der Hanglagen gegenüber Wassererosion gemindert werden können.

10. Obwohl das Segmentpflugprinzip zur Melioration des Bodengefüges entwickelt worden ist, müsste es auf Grund der unter Punkt 7 genannten Wir-

kung auch bei einer bereits entsprechend vertieften Bodenkrume für die normale Bewirtschaftung des Bodens Vorteile bringen. Hierbei wäre es durchaus möglich, den Segmenthobel um 3—5 cm breiter auf 10—12 cm auszulegen und so entweder ständig oder in Etappen bei normalen Pflugtiefen (25—30 cm) etwa ein Drittel der unterhalb dieser Arbeitstiefe gelegenen Bodensubstanz in die Krume einzumischen bzw. „zu wenden". Hierdurch ist eine geringere Entkalkung der Ackerkrume zu erwarten bzw. können die durch Auswaschung möglichen Nährstoffverluste gemindert werden.

Zur Bestätigung dieser zum grössten Teil hypothetischen, wenn auch durch Erfahrungen aus der Praxis und durch unsere bodenphysikalischen Untersuchungsergebnisse begründeten Wirkungen des meliorativen Segmentpflügens und zur langfristigen Prüfung, in welchem Masse das Reduktionspotential der in den Segmenten befindlichen Bodensubstanz vergrössert wird, sind von uns in den vergangenen Jahren mit einem für diese Zwecke umgerüsteten Pflug der D-Reihe des VEB Bodenbearbeitungsgeräte, Leipzig, Feldversuche angelegt worden, über deren Ergebnisse weiter unten noch berichtet wird. Aus den Abbildungen 3—5 sind die Arbeitswerkzeuge des umgerüsteten Pfluges, ihre Anbringung am Pflug und die Wirkung des Pfluges zu erkennen.

Aus der Abbildung 3 ist ersichtlich, dass der Segmenthobel von einem Bügel, der über eine Klaue schwenkbar am Pflugrahmen gelagert ist, getragen wird. Der Segmenthobel (Abbildung 4) ist im Prinzip ein im oberen Abschnitt streichblechartig geformter Nuthobel. Damit in die mit Krumensubstanz zu verfüllende Rinne nicht vorzeitig der von dem Hobel in die Krume beförderte Boden zurückfällt, ist am Hobel seitlich ein Blech angebracht, das die Rinne von der rechten Seite offen hält. An dem Bügel befindet sich ein Ausleger (Abbildung 3) an dem zwei Zugfedern, die ihr Widerlager am Rumpf des Pflugkörpers haben, über zwei Spannbolzen befestigt sind. Durch den Federzug wird der Segmenthobel während des Pflügens in der Arbeitsstellung gehalten. Trifft der Hobel auf Steine, die er nicht an die Oberfläche transportieren kann, so kann er um den in der Klaue befindlichen Drehpunkt nach hinten ausschwenken, wobei die Zugfedern gespannt werden. Nach dem Passieren des Hindernisses wird dann der Hobel durch den Federzug der gespannten Federn wieder in die normale Arbeitsstellung gezogen.

Durch diese Konstruktion ist die normale Pflugfurche selbst auf steinreichen Böden, wie sie in der Grundmoräne vielfach anzutreffen sind, stets gewährleistet. Es ist daher auch nicht erforderlich, die Arbeitsgeschwindigkeit beim Pflügen zu verringern. Nach unseren bisherigen Erfahrungen liegt die beim Pflügen (2 Pflugkörper) erreichbare Hektarleistung bei 0,25—0,3 ha/h. Bei einer 28—30 cm tiefen Pflugfurche ist ein Radtraktor (Zetor) allerdings überfordert, so dass wir zur Anlage unserer Versuche einen Kettenschlepper (KS 30) benutzen mussten.

Mit der Abbildung 5 soll die Wirkung eines mit Segmenthobeln umgerüsteten Pfluges demonstriert werden. An der linken Wand der Profilgrube ist die Ausbildung des Bodenprofils vor dem Pflügen (Bodenkrume etwa 26—27 cm) und an der rechten die Meliorationswirkung zu erkennen. Der Pfeil weist die Pflugrichtung.

Abb. 3. Die Anbringung der zum Segmentpflügen erforderlichen Werkzeuge am Pflug.

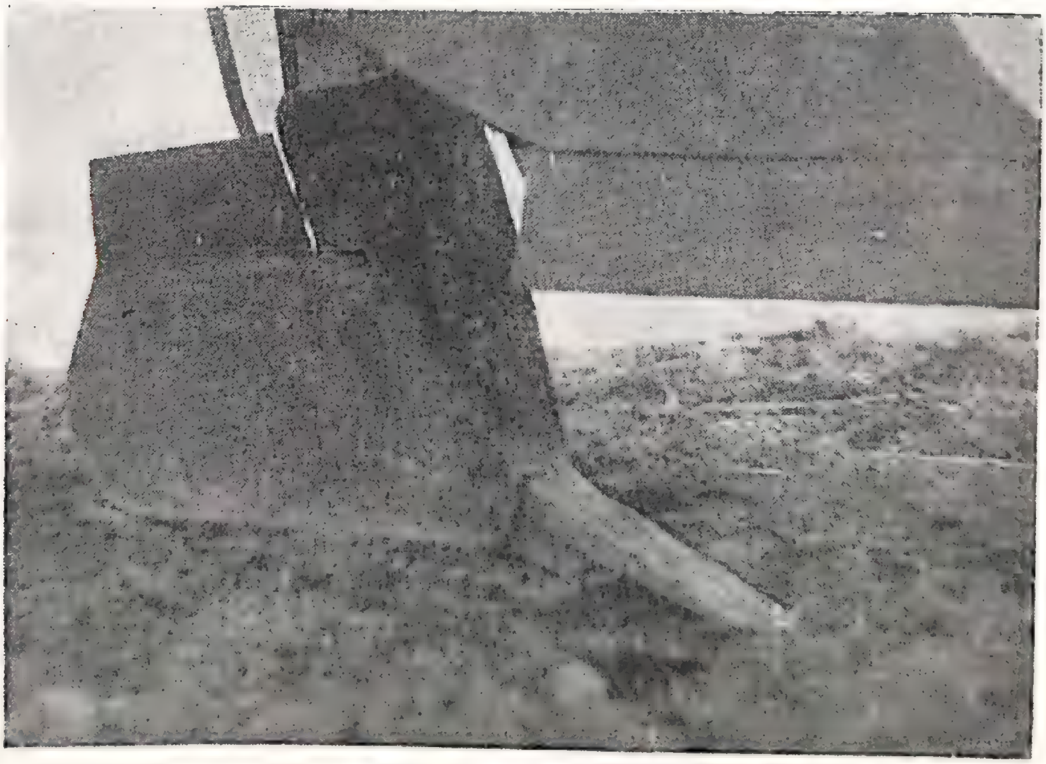

Abb. 4. Der Segmenthobel.

Tabelle 1

Ernteerträge grossflächig angelegter Feldversuche durch melioratives Segmentpflügen

Angebaute Pflanze	Kontrolle 27 (dt/ha)	Segmentpflügen 27 / S 47 (dt/ha)	Ertragsdifferenz durch Segmentpflügen (dt/ha)	P-Wert (%)	Bodenverhältnisse	Zeitpunkt des Pflügens
			1961			
1.1 Silomais	482,7	527,0	+ 44,3	7,3	lS 3D 47/45	Frühjahr
2.1 Silomais	497,0	539,8	+ 42,8	1,7		
.2 Silomais	592,4	612,7	+ 20,3	1,8		
.3 Silomais	605,8	583,5	+ 22,3	19,0	lS 4D 38/34	Frühjahr
			1962			
3.1 Silomais	282,5	13,30	+ 30,5	11,5	lS 4D 38/34 SL 4D 48/47	Frühjahr
4.1 Kartoffeln	333,3	346,7	+ 13,4	20,0		
.2 Kartoffeln	313,7	335,1	+ 21,4	16,3		
.3 Kartoffeln	296,3	333,0	+ 36,7	2,2		
.4 Kartoffeln	280,0	345,0	+ 65,0	1,3	Sl 3D 38/36	Frühjahr
5.1. Zuckerrüben + Blatt	769,2	999,7	+ 230,5	<0,1		
.2 Zuckerrüben + Blatt	869,9	992,3	+ 122,5	<0,1	SL 4D 48/46	Frühjahr
6.1. Zuckerrüben + Blatt	843,2	974,1	+ 130,9	4,3		
.2 Zuckerrüben + Blatt	790,1	853,0	+ 62,9	19,8	Sl 3D 38/36	Frühjahr
7.1. Zuckerrüben + Blatt	972,8	1036,3	+ 63,5	15,8		
.2 Zuckerrüben + Blatt	1004,8	1076,6	+ 71,8	0,7	Sl 3D 38/36	Frühjahr

8.1 Kartoffeln	319,8	326,0	+ 6,2	15,4		
.2 Kartoffeln	309,0	330,5	+ 21,5	15,4	IS 4D 38/34	Frühjahr
			1963			
9.1. Winter Weizen	47,8	55,1	+ 7,3	4,7		
.2 Gemenge	34,3	40,9	+ 6,6	6,2		
.3 Hafer	44,4	50,9	+ 6,5	10,0	IS 4D 38/34	Herbst
10.1 Kartoffeln	354,3	358,1	+ 3,8	13,0		
.2 Kartoffeln	293,7	315,6	+ 21,9	<0,1		
.3 Kartoffeln	201,3	276,9	+ 75,6	<0,1	IS 3D 47/45	Frühjahr
11.1 Zuckerrüben+Blatt	1065,0	1185,0	+ 120,0	<0,1		
.2 Zuckerrüben+Blatt	1067,0	1172,0	+ 105,0	<0,1	IS 4D 38/34	Herbst
12.1 Zuckerrüben	346,0	380,0	+ 34,0	<0,1	IS 4D 43/41	Herbst
13.1 Zuckerrüben	595,0	622,0	+ 27,0	3,1		
.2 Zuckerrüben	594,0	633,0	+ 39,0	0,6	Sl 3D 38/36	Herbst
14.1 Runkelrüben	1060,0	1078,0	+ 18,0	0,7		
.2 Runkelrüben	994,0	1029,0	+ 35,0	4,9	IS 4D 38/34	Herbst
		Nachwirkung im 2. Jahr				
15.1 Sommer Gerste (auf Nr. 5—8)	34,2	38,5	+ 4,3	14,6	Sl 4D 48/46 Sl 3D 38/36	—
16.1 Winter Weizen (auf Nr. 3)	46,2	51,2	+ 5,0	15,0	SL 4D 48/47	—

Abb. 5. Profil eines mit dem Segmentpflug meliorativ gepflügten Bodens.

Aus der Ansicht des Bodenprofils lässt sich unschwer ableiten, dass die Seitenflächen des Bodens durch den Segmenthobel nicht verschmiert sind, sondern dass ein Aufbruch stattgefunden hat, der zu porösen Flächen führt, so dass die Pflanzenwurzeln auch seitlich in den nicht oder wenig vom Hobel gelockerten Boden eindringen können.

Deutlich sichtbar ist weiter der Verbleib des in die Krume eingebrachten Unterbodens, der beim nächsten Pflügen auf die ganze Ackerkrume verteilt werden wird, und in dieser Vegetationsperiode kaum zu Ertragsminderungen führen kann.

Wenn auch aus unseren in den Jahren 1961—1963 durchgeführten Feldversuchen noch nicht abgeleitet werden kann, in welchem Umfang sich die Hektarerträge durch melioratives Segmentpflügen im allgemeinen steigern lassen, so sollen doch die Ergebnisse dieser Versuche hier zur Orientierung mitgeteilt werden (Tabelle 1).

Aus den Versuchsergebnissen — es sind nur die aufgeführt, deren P-Wert < 20 war — kann bereits jetzt abgeleitet werden, dass mit meliorativem Segmentpflügen Mehrerträge erreicht werden, die den Mehraufwand gegenüber normalem Pflügen bei weitem übertreffen. Diese Feststellung gilt, und hierauf sei besonders hingewiesen, sem auch dann, wenn wie bei unseren Versuchen die Ernteerträge bereits bei üblicher Bodenbearbeitung aussergewöhnlich hoch sind.

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ZUSAMMENFASSUNG

Aus den Ergebnissen bodenphysikalischer Forschungen über den Einfluss der Zusammensetzung der Bodensubstanz auf das Gefüge in Ackernutzung befindlicher Böden wird ein qualitativ neuartiges Bodenbearbeitungsverfahren, das meliorative Segmentpflügen, abgeleitet, mit dem eine komplexe Melioration des Bodengefüges der Bodenkrume möglich ist. Nach einer Diskussion der Wirkungen des Segmentpflügens wurden das für dieses Verfahren erforderliche Werkzeug beschrieben und die bisher mit diesem Verfahren erzielten Feldversuchsergebnisse mitgeteilt.

SUMMARY

A qualitative new soil cultivation practice, the ameliorative segment ploughing, allowing a complex amelioration of the top soil structure was deduced as a result of soil physical researches concerning the influence of soil substances composition upon the structure of cultivated soils. After a discussion on segment ploughing effectiveness, the requested machinery is described by the author and results of field experiments are presented.

RÉSUMÉ

Des résultats des recherches sur le physique du sol relatifs à l'influence de la composition du sol sur l'état physique de la couche arable il résulte qu'une nouvelle pratique qualitative pour la culture du sol devient possible.

Après avoir discuté les effets du labour segmentaire, on décrit l'instrument requis par ce procédé ainsi que les résultats des expériences au champ effectuées jusqu'ici selon ce procédé.

DISKUSSION

C. I. FLORESCU (République Populaire Roumaine). Une contribution importante à l'augmentation de la production agricole dans le monde entier est constituée par la lutte contre l'érosion des sols, l'utilisation des irrigations et des engrais, la mécanisation des travaux agricoles, ainsi que la mise en valeur des sols aux propriétés défavorables pour la production agricole. Sur les sols érodés, ou ceux qui ont des propriétés physiques et mécaniques défavorables, les travaux classiques du sol n'assurent pas des productions satisfaisantes.

Les travaux classiques se sont développés pour correspondre en général aux sols considérés comme fertiles. En tout cas, ces travaux et les machines classiques ne peuvent résoudre les problèmes posés par tous les types de sols.

La plupart des études et recherches actuelles ont été entreprises dans le domaine des travaux classiques, ce qui limite leur application pratique. En élargissant le cadre d'aplication des nombreuses connaissances nouvelles dans le domaine de la physique et de la mécanique du sol, on peut modifier le schèma d'exécution des travaux du sol, en tenant compte des nécessités biologiques des plantes agricoles.

Dans ce but on peut considérer le sol comme un milieu physique et mécanique qui aurait deux phases: la phase „travaillée" et la phase „non-travaillée" qui sont entre elles dans des rapports convenables pour les nécessités biologiques des plantes agricoles.

En variant les positions dans l'espace de ces deux phases, on peut élaborer des méthodes de travail du sol, dans lesquelles les rapports quantitatifs existant entre ces deux phases, soient respectés.

Partant de cette hypothèse, nous avons élaboré une méthode de travail discontinu du sol, qui présente la possibilité d'augmenter la profondeur de travail, tout en conservant les rapports quantitatifs entre la phase travaillée et la phase non-travaillée. Nous avons expérimenté cette méthode de travail sur un sol brun podzolisé à pseudogley, à texture fine, peu productif. Sans utiliser des engrais ou des amendements, nous avons obtenu un accroissement du rendement de deux cents trois pour cent, par rapport au témoin labouré de la manière classique. En même temps, on a mis en évidence, à l'aide de recherches sur la pénétrabilité et l'humidité, des similitudes quantitatives entre les propriétés mécaniques des phases mentionnées au sol, labouré de manière classique et les mêmes phases dans le sol travaillé d'après notre méthode.

Les recherches de cette nature ont besoin d'une expérimentation plus prolongée pour pouvoir être généralisées.

Cette méthode de travail discontinu du sol est en cours d'expérimentation dans quelques-unes de nos stations de recherches.

COMMISSION VI

SOIL TECHNOLOGY

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

THE INFLUENCE OF SOIL PHYSICAL PROPERTIES ON RUNOFF, EROSION, AND INFILTRATION OF SOME SOILS IN THE SOUTHEASTERN UNITED STATES [1]

A. R. BERTRAND, A. P. BARNETT, J. S. ROGERS [2]

Sound planning of soil and water conservation and management programs requires accurate knowledge of the soil behaviour under specified use and climatic conditions. Empirical equations for field soil-loss estimates (Browning, Parish and Gloss, 1947; Musgrave, 1947; Von Doren Bartelli, 1946) have become valuable tools in the hands of trained workers in conservation planning. The equation most widely used for predicting soil loss in the United States (Wischmeier, 1959; Wischmeier and Smith, 1960) requires numeral evaluation of erosionproducing capacity of rainfall, soil erodibility, crop management, slope, and conservation practices to retard runoff and erosion. The reliability of soilloss estimates can be substantially increased by improving the reliability of individual values comprising the prediction equation.

The study reported here was designed primarily to secure absolute value from fallow soils in the Southeastern United States for the soil erodibility factor in the erosion prediction equation. Several soil characteristics, determined by routine laboratory procedures, have been considered indicative of the soil's erodibility (Middleton, Slater and Byers, 1932, 1934). Many of these characteristics were measured in this study. This report presents an examination of relationships between soil characteristics and soil loss, runoff, and infiltration.

METHOD AND PROCEDURE

Field Procedures

Runoff, soil loss, infiltration, and other pertinent data were collected through the use of a field plot rainfall simulator (rainulator) (Hermsmeier, et al., 1963; Meyer and Mannering, 1960) at sites located in the Southern

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[1] Contribution from the Southern Branch, Soil and Water Conservation Research Division. Agricultural Research Service, USDA, in cooperation with the Georgia Agricultural Experiment Stations. For presentation at the VIIIth International Congress of Soil Science, Bucharest, Rumania, August 31—September 9, 1964.

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Piedmont and Southern Coastal Plain Land Resource Areas. Soils were selected on the basis of agricultural importance and range of physical properties. A total of 13 soil types on 35 sites were studied. These soils ranged in texture from loamy sand to sandy clay loam and were located on slopes of 2 to 8% (table 1). Cropping history of each site was determined by interviews with land owners. The ideal site was one that had been in continuous rowcrops — preferably cotton *(Gossypium hirsutum* L.*)* or corn *(Zea mays* L.*)* — for at least three years at a moderate to low fertility-management level. This was not always achieved. In some cases idle land was used and in a few others, rowcrop rotations of corn and soybeans *(Glycine max* Merr.) or cotton, oats *(Avena sativa* L.) and soybeans were selected. Where cropping histories differed from site to site, cropping factor values were assigned using the procedures outlined by Wischmeier (1960). Characterization of the soil on each site included:

1) preparation of a complete profile description, including all observable morphological characteristics of each horizon;

2) laboratory determinations of the following physical properties of each horizon: bulk density, per cent moisture retained against 1/3, 2, 4, 8, 15 bars suction, and per cent sand, silt, and clay (table 2). The sand fraction in the Ahorizon of each site was separated further into five size ranges by dry seiving.

Soil on each site was turn-plowed with a moldboard plow and smoothed with a disk harrow in the spring. Sites were maintained fallow and weed-free until erodibility tests were made with a rainulator in July and August.

Just prior to final smoothing of the plot surface and application of simulated rainfall, samples of the 0 to 2-inch layer of soil were taken for additional physical and chemical determinations. Samples of the 0 to 3-inch and 3 to 6-inch soil layers were taken for antecedent moisture determinations.

Final plot preparation was accomplished by pulling a spiketooth harrow over the plot surface in a direction parallel to the land slope. Each field site consisted of two plots, 12 feet wide and 35 feet long, separated by a 6-foot alleyway. Runoff collection flumes were located at the lower edge of each plot and runoff-recording instruments and soil-sampling devices were located in a pit 10 feet downslope from the flume. The rainulator was erected directly over the plots (fig. 1). Four periods of rainfall, each of 30 minutes duration and separated by 10-minute intervals without rain, comprised the test storm in these studies. Rainfall intensity was approximately 2.5 inches per hour. For the purpose of this paper, all four rainfall increments were combined and treated as one storm with 5.0 inches of rain in 120 minutes: the 10-minutes intervals of no rain between increments were ignored. A typical hydrograph showing runoff and infiltration curves for a test storm is shown in figure 2.

Rainfall amount was measured with diagonal collection troughs set 10 to 14 inches above the plot surface and emptied into covered buckets at the edges of the plots.

Table 1

A sumary of soils studied, and pertinent soil, soil-loss, runoff, and infiltration data

Great Soil Group	Soil Series name	Textural Range classes	Sites no	Slope Range %	Range in Soil Loss per EI t/ac EI	Runoff* %	Infiltration** %	Final Infiltration Rate* i ph
Regosol (Entisol) **	Lakeland	ls	4	2.7—5.8	.010—.102	38.8	61.2	1.27
Planasol (Udolf)	Iredell	fsl-sl	3	2.4—4.0	.024—.076	72.5	27.5	.46
Planosol (Utisol)	Helena	csl-sl	3	6.0—6.8	.093—.153	66.8	33.2	.67
Reddish-Brown Lateritic (Utisol)	Lloyd	sl-scl	4	4.0—7.7	.016—.097	63.0	37.0	.76
Reddish-Brown Lateritic (Udalf)	Mecklenburg	scl	1	2.7	.030	61.5	38.5	.74
Red & Yellow Podzolic (Utisol)	Cecil	sl	2	6.4—7.8	.079—.098	69.8	30.2	.60
Red & Yellow Podzolic (Utisol)	Faceville	ls	1	2.4	.028	71.8	28.2	.44
Red & Yelloow Podzolic (Utisol)	Georgeville	sil	3	3.6—8.0	.088—.219	71.2	28.8	.46
Red & Yellow Podzolic (Utisol)	Herndon	sil-sicl	3	4.4—5.3	.061—.085	72.2	27.8	.43
Red & Yellow Podzolic (Utisol)	Marlboro	ls-sl	2	3.3—3.5	.027—.039	43.3	56.7	1.20
Red & Yellow Podzolic (Utisol)	Norfolk	sl-ls	3	4.5—5.0	.021—.062	53.1	46.9	.83
Red & Yellow Podzolic (Utisol)	Norfolk	ls (thick surface)	3	2.6—3.7	.026—.089	47.4	52.6	1.18
Red & Yellow Podzolic (Utisol)	Tifton	ls	3	1.8—4.6	.024—.100	61.6	38.4	.66

* 5 inches of rainfall was applied on each test at a rate of 2 1/2 in/hr. (Averages for all sites).
** Soil order according to the New Comprehensive soil Classification System (7 th Aproximation, August 1960).

Table

Physical characteristics of soils used in soil erodibility

Soil Series	Site	Organic Matter %	Bulk Density gm/cc	Moisture %		Suspension Percentage		Clay %
				1/3 Atm.	15 Atm.	50 μ	20 μ	
Lakeland	1	0,6	1.55	4.0	2.0	5.7	2.7	11.9
	2	0.6	1.56	4.6	2.0	4.6	2.2	9.6
	3	0.7	1.46	4.6	2.0	6.9	3.1	5.6
	4	1.2	1.50	6.7	2.7	9.3	5.4	9.7
Tredell	1	1.0	1.67	20.4	10.8	14.8	4.8	11.4
	2	1.4	1.54	28.0	15.7	15.3	4.8	19.8
	3	1.2	1.61	22.9	10.2	16.7	5.7	16.0
Helena	1	0.8	1.56	8.5	3.3	13.6	4.4	7.1
	2	1.2	1.39	18.7	6.3	13.3	6.0	18.1
	3	1.0	1.47	9.4	3.3	11.5	6.2	11.3
Lloyd	1	1.4	1.52	23.5	13.8	14.9	5.8	27.0
	2	1.6	1.40	20.4	12.4	9.1	2.6	22.7
	3	1.8	1.53	29.7	12.4	10.2	4.0	23.7
	4	1.1	1.59	10.8	5.2	16.9	12.1	16.9
Mecklen-burg	1	1.1	1.50	14.2	9.4	19.1	7.4	23.7
	2							
Cecil	1	1.4	1.55	22.3	11.3	8.9	3.6	18.0
	2	1.2	1.60	24.5	14.1	9.5	4.0	19.7
Faceville	1	0.8	1.76	6.5	2.5	12.5	5.8	7.7
George-ville	1	1.4	1.40	28.5	9.0	40.7	18.6	20.9
	2	1.8	1.28	34.3	10.4	30.5	13.8	24.1
	3	1.4	1.30	27.1	7.7	44.9	19.6	17.9
Herndon	1	2.1	1.39	32.1	9.0	32.6	16.0	16.2
	2	2.0	1.29	44.9	14.0	33.2	19.0	28.0
	3	1.2	1.47	20.9	6.0	38.8	20.6	20.0
Marlboro	1	0.8	1.66	4.0	2.8	8.3	4.2	8.9
	2	2.2	1.50	10.5	4.1	12.7	6.8	16.1
Norfolk	1	1.0	1.58	10.2	4.3	16.8	7.6	9.7
	2	1.1	1.63	7.6	3.6	9.5	5.0	7.4
	3	0.8	1.70	9.1	3.8	11.0	6.2	10.5
Norfolk (thick phase)	1	0.7	1.66	3.3	1.8	9.2	4.6	10.1
	2	0.9	1.68	4.6	2.1	8.9	6.5	10.6
	3	0.3	1.54	3.8	1.7	8.8	6.5	10.9
Tifton	1	1.1	1.69	4.6	2.3	9.7	5.6	11.9
	2	1.0	1.70	5.3	2.9	9.6	5.0	11.2
	3	1.1	1.76	5.6	2.9	6.3	2.5	12.1

2

studies, Southern Piedmont Station (1962—1963)

Silt %	Sand %	vfs %	fs %	ms %	cs %	vcs %	2mm — 4.76 mm %	>4.76mm %
2.0	86.1	7.3	27.5	32.4	16.4	2.2	.2	0
1.8	88.6	7.4	30.1	32.8	14.7	2.8	.8	0
6.4	88.0	9.4	32.1	29.7	13.4	3.1	.3	0
5.9	84.4	7.7	24.0	30.5	18.0	3.9	.3	0
23.2	65.4	11.0	18.3	11.1	10.4	10.6	3.6	.4
23.8	56.4	9.3	16.7	10.8	7.2	5.8	3.6	3.0
24.9	59.1	10.8	17.2	9.7	10.0	7.8	2.8	.8
12.3	80.6	21.0	27.1	17.6	9.9	3.5	1.3	.1
21.2	60.7	6.3	12.5	15.2	15.3	6.8	2.1	2.5
10.3	78.4	8.1	16.3	20.5	26.6	6.0	.6	.5
17.0	56.0	4.2	14.2	16.2	12.2	4.8	1.4	2.6
14.8	62.5	5.1	16.8	17.0	9.9	7.6	5.0	1.1
13.9	62.4	5.2	16.6	18.1	12.8	5.8	1.8	2.1
12.7	70.4	6.5	15.1	17.3	17.3	8.5	3.7	2.0
18.7	57.6	9.2	16.9	13.3	9.2	5.4	3.0	.6
9.2	72.8	5.2	18.0	23.4	13.6	7.2	4.0	1.4
9.8	70.5	5.8	24.8	26.4	7.7	3.0	1.7	1.1
8.8	83.5	12.8	24.7	20.6	10.7	5.6	2.8	6.3
57.8	21.3	11.6	4.7	2.0	1.2	1.0	.6	.2
64.3	11.6	6.6	2.3	1.0	.7	.4	.4	.2
56.7	25.4	13.8	5.0	2.0	1.4	1.2	1.0	1.0
50.3	33.5	7.0	4.4	2.6	5.3	6.2	4.4	3.6
55.8	16.2	6.4	3.6	1.6	1.2	1.0	1.0	1.4
51.1	28.9	6.8	4.5	1.9	1.6	1.7	3.8	8.8
1.8	89.3	14.4	32.7	27.4	13.0	1.6	.2	0
10.0	73.9	6.1	19.4	20.8	10.4	5.2	3.4	8.6
11.4	78.9	15.5	24.9	20.2	11.9	3.5	1.0	1.6
6.7	85.9	9.5	24.0	25.7	20.2	5.2	.9	.4
7.9	81.6	10.1	21.6	19.8	14.0	9.4	4.5	2.2
4.1	85.8	14.7	36.8	25.4	7.6	1.1	1.2	.0
4.2	85.2	5.8	17.0	22.8	24.0	10.9	4.0	.7
1.0	88.1	10.6	47.4	20.9	7.9	1.3	.1	.3
5.0	83.1	12.0	35.6	22.5	7.0	2.1	.8	3.1
4.1	84.7	11.5	33.2	24.4	7.4	1.8	1.5	4.9
5.1	82.8	5.6	22.4	23.5	6.9	2.2	1.9	20.3

Total runoff was calculated from time-gage height data obtained from the water-stage recorder and a rating curve for the measuring flume. Soil carried in the runoff during each 5 minutes of the storm was collected throughout each test with a modified Coshocton wheel (Hermsmeier et al., 1963).

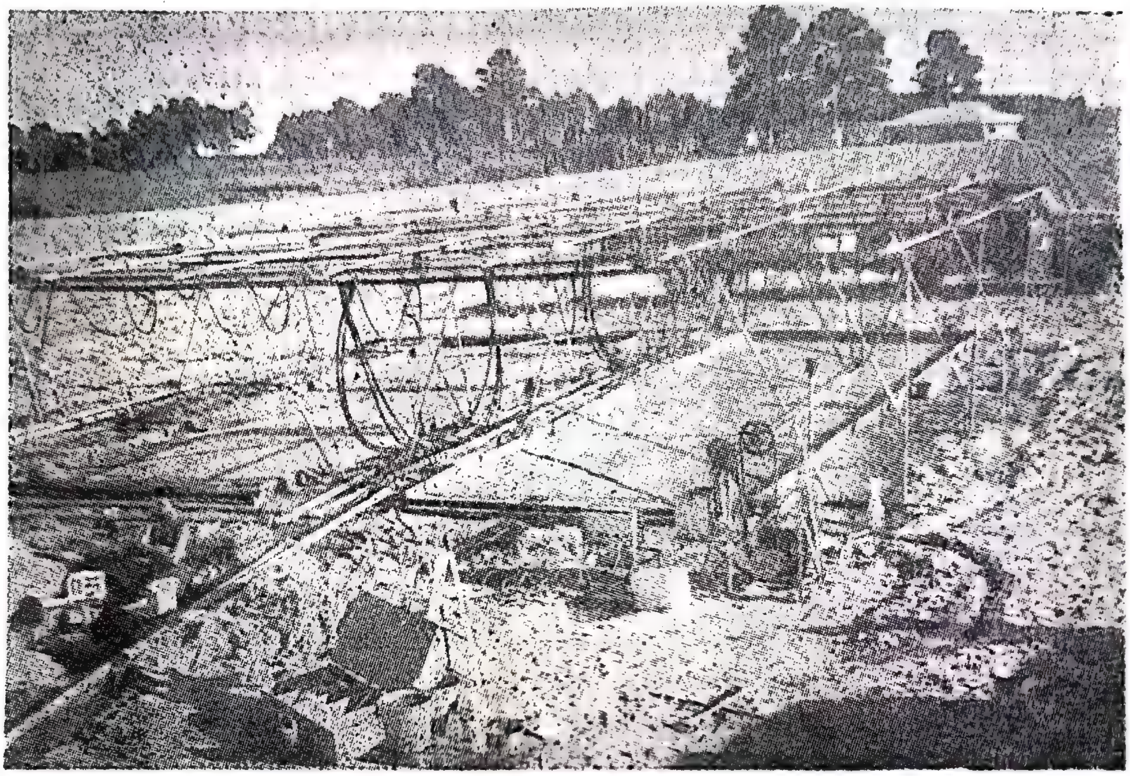

Fig. 1. Rainulator erected at a field site.

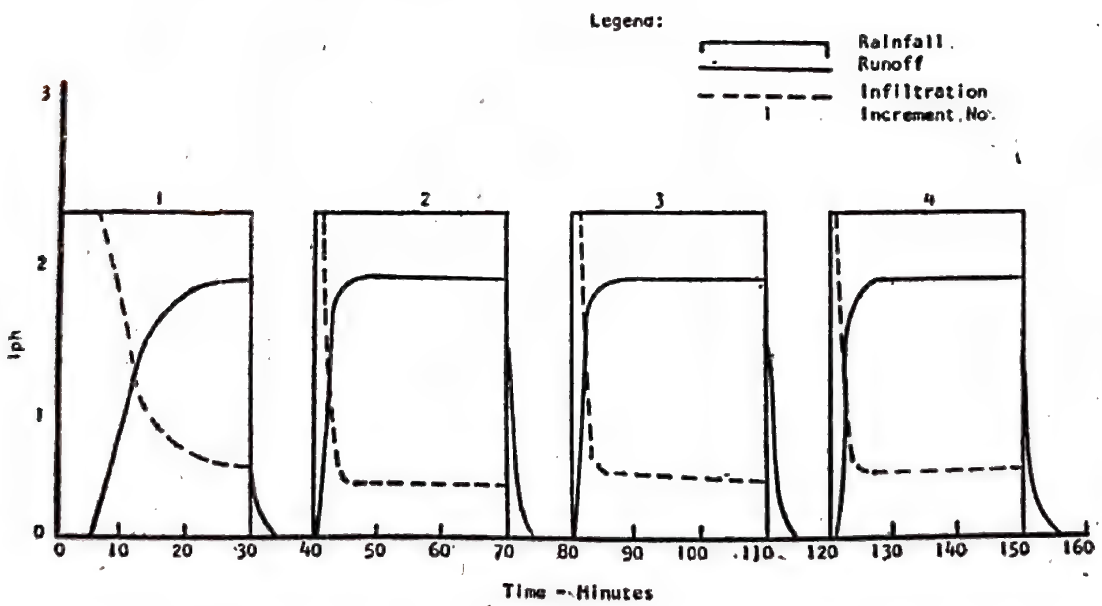

Fig. 2. A typical hydrograph for a soil erodibility test.

Data Processing

Twenty-one primary factors and 19 transformations of the primary factors for a total of 40 variables (table 3) were correlated with runoff and soil loss. Since rainfall amount was constant and infiltration was derived from the difference between amount of rainfall and runoff, correlation coefficients for both runoff and infiltration were not calculated. A stepwise regression procedure (Baer, John and Tornheim, 1962; Efroymson, 1960) was used to select the best-fit variables in the regression analysis.

RESULTS AND DISCUSSION

Ranges in soil loss per erosion index unit (EI) (W. H. Wischmeier 1959) percent runoff, percent of water entering the soil profile, and final infiltration rate, are presented in table 1. Soil loss per El unit was used in this analysis, thus removing the influence of slight variations in rainfall amount and intensity and placing each site on an equal energy-intensity basis.

Soil Loss

Ten variables (Items No. 4, 9, 15, 20, 25, 26, 29, 33, 34 and 36 in Table 3) explained 89.5% of the variation in soil loss per EI among the various sites with a standard error of .017 ton per acre per EI unit. When 9 other variables (Items 2, 3, 6, 12, 14, 17, 22, 38 and 40) were added and one of the original 10 (Item No. 25) variables was deleted, 97.5% of the variation in soil loss between sites was explained (table 4) with a standard error of .010 ton per acre per EI unit.

The coefficients for each variable, the standard error of the coefficient, and the amount that R^2 would be reduced if a given variable were deleted from the equation, are presented in table 4.

Since most of the soils included in this study were rather sandy, bulk density was negatively correlated with both soil loss and runoff (table 3, Item 17); however, when all other variables were held constant and only bulk density varied in the regression analysis, the regression coefficients became positive (tables 4 and 5).

The equation for predicting soil loss per El with these 18 variables has the form:

$$A = c + b_1 x_1 + b_2 x_2 + \dots + b_{18} x_{18},$$

where A is soil loss in tons per acre per EI unit,
c is a constant (table 4),
$b_1, \dots, b_{18}$ are regression coefficients (table 4),
$x_1, \dots, x_{18}$ are independent variables (table 4).

Numerical values for x variables are shown in table 2.

Table 3

Correlation coefficients*of 21 soil and rainfall properties and 19 transformations with runoff amount and soil loss per acre per erosion index unit

		Runoff Amount	Soil Loss/ Acre EI
1	% material $> 4760\ \mu$	.192	—.206
2	% material 2000—4760 μ	.323	—.344
3	% very coarse sand	.156	—.363
4	% coarse sand	—.328	—.153
5	% medium sand	—.596	—.283
6	% fine sand	—.612	—.361
7	% very fine sand	—.183	.080
8	% sand	—.569	—.412
9	% silt	.520	.420
10	% clay	.540	.267
11.	1/3 atm moisture percentage	.622	.324
12.	15 atm moisture percentage	.606	.189
13.	50 μ suspension percentage	.467	.408
14.	20 μ suspension percentage	.375	.331
15.	Rainfall amount	.150	—.216
16.	Slope	.201	.695
17.	Bulk density	—.141	—.393
18.	Depth of A horizon	—.721	—.066
19.	% carbon	.523	.163
20.	% moisture 0—3" depth/1/3 atm. moisture %	—.465	—.185
21.	moisture 3—6" depth/1/3 atm moisture %	—.465	—.311
22.	% sand/(% silt + % clay)	—.764	—.324
23.	% silt (% sand + % clay)	.432	.441
24.	% clay (% sand + % silt)	.523	.257
25.	$\log_e$ % material 2000—4760 u	.505	—.226
26.	$\log_e$ % very coarse sand	.079	—.379
27.	$\log_e$ % coarse sand	—.361	—.356
28.	$\log_e$ % medium sand	—.479	—.372
29.	$\log_e$ % fine sand	—.527	—.406
30.	$\log_e$ % very fine sand	—.198	.056
31.	$\log_e$ % sand	—.474	—.420
32.	$\log_e$ % silt	.718	.331
33.	$\log_e$ % clay	.569	.284
34.	slope^2	.246	.713
35.	$\log_e$ slope	.145	.653
36.	$\log_e$ bulk density	—.150	—.390
37.	$\log_e$ 50 μ suspension %	.580	.347
38.	$\log_e$ 20 μ suspension %	.426	.281
39.	$\log_e$ % carbon	.614	.192
40.	$\log_e$ 1/3 atm moisture %	.682	.313

* r. 05 = . 335.
r. 01 = . 431.

Actual versus predicted values for this equation are shown in figure 3. The use of this equation to predict soil loss per EI requires data that can be acquired by securing field samples for mechanical analysis, moisture desorp-

Table 4

Variables and coefficients for the soil loss equation

X_n	Variable	b_n	S_b	Delta R^2
1	% material 2,000—4,760 μ	.0327	.0052	—.0626
2	% very coarse sand	—.0140	.0035	—.0246
3	% coarse sand	—.0124	.0017	—.0794
4	% fine sand	—.0074	.0016	—.0364
5	% silt	.0103	.0011	—.1294
6	15 atm moisture %	—.0083	0.020	—.0277
7	20 μ suspension %	—.0177	.0029	—.0585
8	rainfall amount	—.0264	.0106	—.0097
9	bulk density	1.3378	.5515	—.0093
10	% moisture 0—3" depth/1/3 atm. moisture %	.0754	.0123	—.0594
1	% sand (% silt + % clay)	0.236	0.057	—.0270
12	$\log_e$ % very coarse sand	—.0582	.0134	—.0298
13	$\log_e$ % fine sand	.2696	.0317	—.1147
14	$\log_e$ % clay	.0679	.0159	—.0288
15	slope^2	.0022	.0002	—.2354
16	$\log_e$ bulk density	—1.8197	.8555	—.0072
17	$\log_e$ 20 μ suspension %	.1229	.0228	—.0458
18	$\log_e$ 1/3 atm moisture %	.1032	.0220	—.0347

Constant = — 2.5866. R^2 = .975.
Standard error of regression Y = .01014.

tion characteristics, and bulk density. Determinations required to secure these essential data are routine in most soils laboratories.

Slope squared was the most important variable for explaining variation in soil loss per EI unit, clearly indicating that the effect of slope is not a linear function.

Textural analysis is an extremely important factor in determining erosivity of a soil. As percent silt increased, soil loss increased. In general, as the percentage of sand increased, soil loss decreased. Individual sand size classes, however, do not follow this general pattern. Note the coefficients for the sand size fractions in table 4. The $\log_e$ of per cent fine sand was the third variable in order of importance in accounting for soil loss. Soil loss increased as the variable increased.

Percentage of coarse sand was the fourth variable in order of importance, with soil loss increasing as this variable increased. The fifth variable was the percentage of material in the size range between 2,000 and 4,760 μ. Again soil loss increased as this variable increased. As initial soil moisture

content increased, soil loss increased. The sandy soily in a dry condition had higher initial intake rates, resulting in low runoff rates and low erosion. However, when these sandy soils were wet they eroded as rapidly as the silt soils.

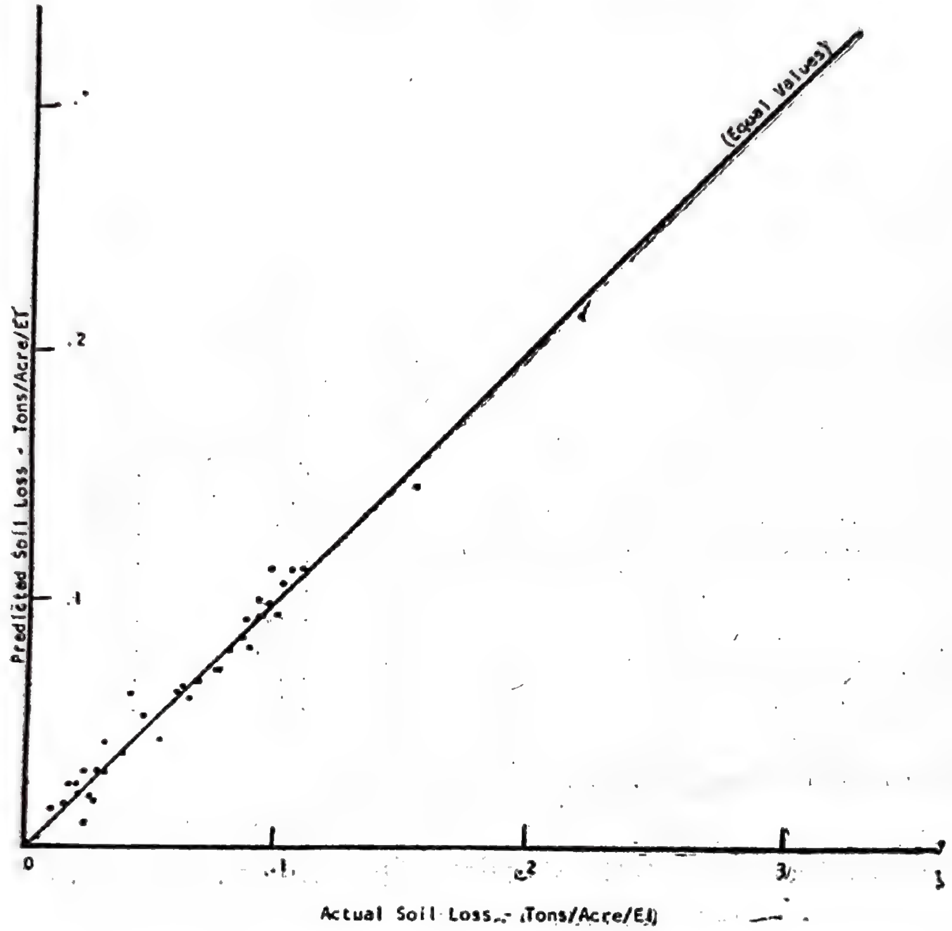

Fig. 3. Actual versus predicted soil loss in tons per acre per El unit.

Runoff

In the regression analysis on runoff seven variables (Items No. 4, 6, 7, 17, 22, 26, and 32 in table 3) explained 89,5% of the variation with a standard error of 27 inch.

When 10 other variables (Items 1, 14, 15, 21, 24, 33, 35, 36, 37 and 40) were added and one of the original 7 (Item 22) variables was deleted, 96,3% of the variation was explained with a standard error of 0,20 inch. The coefficients for each variable, the standard error of the coefficients, and the amount R^2 would be reduced if a variable were deleted from the equation, are presented in table 5.

The equation for predicting runoff from these data has the form

$$R = c + b_1x_1 + b_2x_2 \dots + b_{16}x_{16},$$

where R is runoff in inches,
c is a constant (table 5),

$b_1, \dots, x_{16}$ are regression coefficients (table 5),
$x_1, \dots, x_{16}$ are independent variables (table 5).

Table 6

Variables and coeficients used in the runoff equation

X_n	Variable	b_n	S_b	Delta R^2
1.	% material > 4760 μ	.0335	.0144	—.0111
2.	% coarse sand	.1015	.0173	—.0703
3.	% fine sand	.0539	.0145	—.0282
4.	% very fine sand	—.0691	.0208	—.0225
5.	% 20 μ suspension	—.0538	.0308	—.0062
6.	rainfall amount	.6062	.2065	—.0176
7.	bulk density	20.902	8.8591	—.0113
8.	moisture % 3—6" depth	.7293	.1841	—0.321
9.	% clay/(% sand + % silt)	—8.5853	1.9022	—.0417
10.	$\log_e$ % very coarse sand	—.4684	.0982	—.0465
11.	$\log_e$ % silt	1.1144	.1824	—.0763
12.	$\log_e$ % clay	1.8380	.3939	—.0445
13.	$\log_e$ slope	.7626	.1758	—.0385
14.	$\log_e$ bulk density	—.0026	.0014	—.0070
15.	$\log_e$ 50 μ suspension %	.9161	.3856	—.0115
16.	$\log_e$ 1/3 atm. moisture %	.6436	.2539	—.0131

Constant = — 33.447. R^2 = .963.
Standard error of regression Y = .199.

Actual versus predicted values for this equation are shown in figure 4. Data for substitution in this equation can be obtained by determining antecedent moisture content, moisture desorption characteristics, bulk density, 20μ suspension percentage, and particle size distribution of the field soil. In addition, soil slope and amount of rainfall must be known.

Runoff decreased with an increase in percentage of total sand. When sand was broken down into 7 size classes, there was an increase in runoff with increase in percentage of coarse sand and fine sand. There was also an increase in runoff with an increase in percentage of material greater than 4,760 μ. Runoff decreased with an increase in the $\log_e$ of the percentage of very coarse sand. Thus, it appears that a high percentage of material larger than very coarse sand increases runoff, as do coarse and fine sand fractions, while the very coarse and very fine sand fractions decrease runoff.

Runoff increased as the percentage of silt increased- The $\log_e$ of per cent silt was the best variable in the final equation for predicting runoff. Thus, there was an exponential relationship between runoff and percentage of silt.

Runoff and per cent clay are also exponentially related. The $\log_e$ of per cent clay was the fourth variable in order of importance in the final runoff equation. As the ratio of clay to sand plus silt increased, runoff decreased.

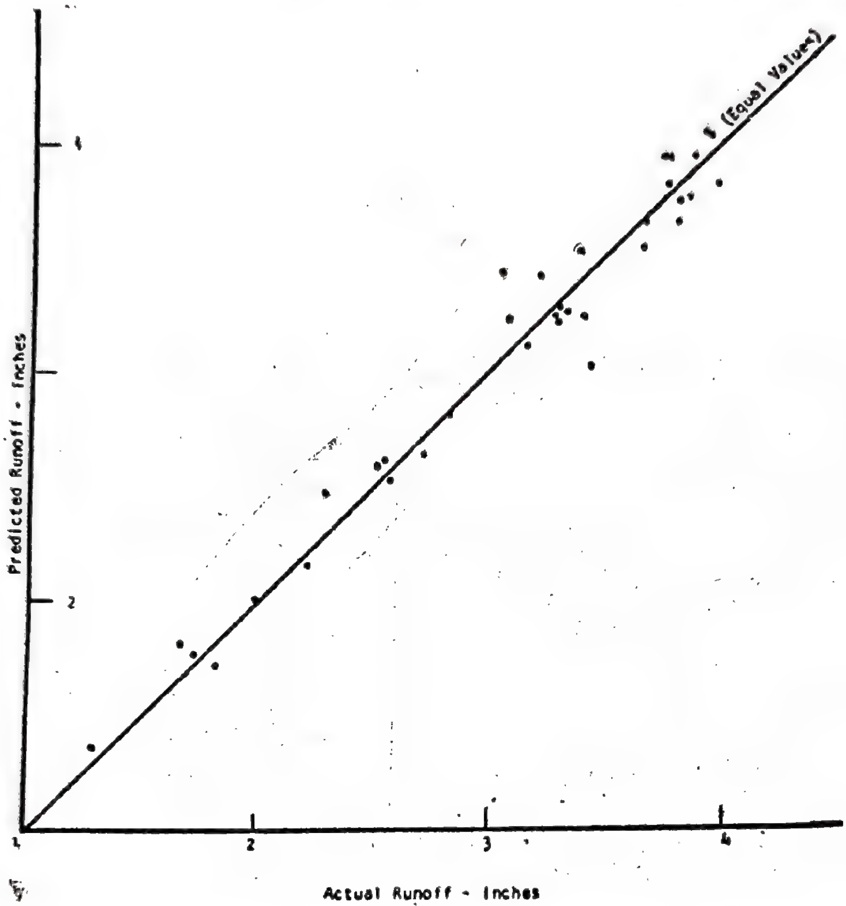

Fig. 4. Actual versus predicted runoff of simulated rainfall using the rainulator.

There was inverse linear relationship of runoff with the 20 μ suspension percentage, while there was an exponential relationship with the 50μ suspension percentage.

As bulk density increased runoff increased at something less than a linear rate, as indicated by the positive linear term for bulk density and the negative log term for bulk density.

Even though the coefficient of correlation between runoff and organic carbon is significantly positive (table 3), this value is considered unrealistic because the range of values for organic matter [1] (table 2) was too small to give a clear relationship. Soil samples would have to be drawn from a much larger area than that used in this study to provide a wide range of soil or-

[1] Per cent carbon was used in the correlation and regression analyse. Per cent organic matter was calculated as 1.724 times per cent carbon.

ganic matter contents. In the Southeastern United States latitude, day lenght, rainfall, and other climatic factors combine to make soil organic matter a rather stable and small soil fraction.

Infiltration and soil physical properties

Although no analyses were made on infiltration directly, there was a high correlation ($r = -.90$) between runoff and total infiltration. Thus, factors that affect runoff would also affect total infiltration. Total infiltration was highly correlated ($r = .92$) with the infiltration rate after 60 minutes of rainfall. Thus, we can infer that factors that increase runoff decrease infiltration and vice versa.

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SUMMARY

Soil erosion, infiltration and several soil properties were determined on 13 soil types at 35 locations in the Southeastern United States.

Ten readily obtainable soil characteristics explained 89.5% of the variation in soil loss. Additional variation was explained by the addition of other variables.

Seven variables explained 89.5% of the variation in runoff. Addition of 9 other variables increased the percent of variation explainable to 96.3%.

Total infiltration and runoff are highly correlated, as are total infiltration and infiltration rate after 60 minutes of rainfall. If these equations for predicting soil loss and runoff continue to prove satisfactory when tested against additional data, the long awaited use of soil physical properties in prediction of runoff and soil loss may be near.

RÉSUMÉ

L'érosion du sol, l'écoulement ,l'infiltration et certaines propriétés du sol ont été determinés sur 13 types de sols à 35 stationnaires dans le sud-est des États-Unis. Dix caractéristiques du soel, faciles à obtenir, ont expliqué 89,5% de la variation dans les pertes de sol. Des variations additionelles ont été expliquées par l'addition d'autres variables.

Sept variables ont expliqué 89,5% de la variation de l'eau d'écoulement. L'addition de 9 autres variables ont augmenté le pourcentage de la variation expliquable à 96,3%.

L'infiltration totale et l'eau d'écoulement sont en corelation étroite, pareilles à l'infiltration totale et la vitesse d'infiltration après 60 minutes de pluie.

Si ces équation en vue de prévoir les pertes de sol et l'eau d'écoulement s'avéreront comme satisfaisantes par rapport aux données supplémentaires, dans ce cas, l'utilisation des propriétés physiques du sol, si ardamment attendue afin de prévoir l'eau d'écoulement et la perte de sol, pourra se produire dans un bref délai.

ZUSAMMENFASSUNG

Bodenrodierung, Abfluss, Einsickerung und andere Bodeneigenschaften wurden an 13 Bodentypussen in 35 Lagen in den südöstlichen Staaten der USA bestimmt.

Zehn leicht erlangbare Bodeneigenschaften erklärten 89,5% der Variationen des Bodenverlustes. Zusätzliche Variationen wurden durch das Hinzutreten anderer Veränderungsgrössen erklärt.

Sieben Veränderungsgrössen erklärten 89,5% der Variationen im Abfluss. Der Zusat anderer 9 Veränderungsgrössen steigerte den Prozentsatz der erklärbaren Variationen auf 96,3%

Totale Einsickerung und Abfluss stehen in enger Wechselwirkung, ebenso wie totale Einsickerung und Infiltration sgeschwindigkeit nach einem 60 Minuten-Regenfall.

Sollten sich diese Gleichungen, Bodenverlust und Abfluss vorherzusagen, auch weiterhin durch zusätzliche geprüfte Daten als befriedigend beweisen, so würde man der lang erwarteten Nutzung bodenphysikalischer Eigenschaften in der Vorhersage von Abfluss und Bodenverlust näherkommen.

DISCUSSION

P. CELESTRE (Italy). I appreciate paper 1 as a very accurate and interesting experimental study. Anyway the exploitation — so to say — of experimental data appears critical and raises some doubts. If a rightful method is not used, the equations fit the particular experiences but have no general validity.

From this point of view I observe:

1. The equations of the numerous variables have linear form.

This raises the main doubt, though of course the correlation satisfies the present experimental datas.

2. The chosen variables correspond sometimes to $\log_e$ of the values sometimes to other functions.

How can their unique validity be assured?

A. R. BERTRAND. 1. Your observation is correct. The approach used was empirical. The cubic and quadratic forms of the equation were studied. Their use did not materially improve the overall correlation coefficient therefore they were not indicated in the paper.

2. Each variable was inserted without modification, their variation were indicated and only when it materially improved the correlation coefficient. A rational explanation for the exact role of each function is not attempted at this stage of our research.

G. W. HOLMES (Australia). What water quality was used in the rainfall water simulator, and was it found to be important to control the salt content in the infiltration meas rements.

A. R. BERTRAND. The water used came from a small stream. Judging from stream water quality in this region, its soluble salt content was very small. There was no important influence of water quality on the experimental measurements.

W. H. VAN DER MOLEN (Netherlands). Are the different factors, introduced in the statistic analysis, mutually interrelated? If this is the case, it is no wonder that the introduction of more factors does not provide additional information.

A. R. BERTRAND. This is correct. In multiple regression analysis, addition of other positively correlated factors increases the corelation coefficient. I believe that the practical approach may be to use only those factors easily acquiered and adding to the correlation coefficient.

F. FOURNIER (France). Peut-on considérer que les résultats obtenus avec les pluies artificielles sont applicables au milieu naturel? En particulier, a-t-on comparé les résultats obtenus des parcelles recevant des pluies artificielles et ceux des pluies naturelles?

A. R. BERTRAND. The energy of rainfall applied by the simulator is approximately 0.8 of natural rainfall. Erosion is in proportion to rainfall energy.

UNTERSUCHUNGEN ÜBER WINDEROSION MITTELS DES „DEFLAMETERS"

H. UGGLA, H. PIASCIK [1]

In vielen Gegenden, insbesondere aber in den Sandgebieten der nördlichen und nordöstlichen Region Polens, wie: Pomorze, die Seengebiete von Masuren und Suwalki, die Kurpische Niederung, treten im Frühjahr heftige, den Boden austrocknende Winde auf. Während dieser Trockenwehen werden aus den dürftigen Sandböden die wertvollsten Mineral-und Humusteilchen ausgeweht. Die schwersten Schäden entstehen im Frühling, unmittelbar nach der Schneeschmelze, sobald der Boden abgetrocknet ist, bevor sich jedoch die Wintersaaten bestockt haben. Manchmal findet das Sandwehen während des Sommers oder des Winters statt (wenn die Schneedecke dünn ist, die Kuppen der sandigen Hügel jedoch bereits schneefrei sind).

Während der Deflation werden nicht nur Bodenteilchen, ja ganze Pflanzen ausgeweht, junge Saaten mit Sand überdeckt oder durch die vom Wind getriebenen Sandkörner mechanisch beschädigt. Die Winderosion und deren Bekämpfung wird in der Literatur eingehend behandelt (Bennet, 1955; Hajime; Jakubov, 1960; Russell, 1958; Smirnowa, 1960; Sobolev, 1948; Uggla und Nożyński, 1959; Torstensson und Nilsson, 1956).

DAS DEFLAMETER

Laufende Untersuchungen dieser für die Landwirtschaft so schädlichen Erscheinungen werden im Institut für Bodenkunde an der Landwirtschaftlichen Hochschule in Olsztyn ununterbrochen seit dem Jahre 1956 bis zum heutigen Tage geführt, mit dem Ziel entsprechende Methoden auszuarbeiten, die es ermöglichen, dieser Erosionsform wirksam entgegenzuarbeiten.

Die Untersuchungen haben den Wissenschaftlern dieses Institutes ermöglicht den Bau eines Modells in Angriff zu nehmen, das geeignet wäre, Bodenteilchen, die durch den Wind von dem Auswehgebiet abgefegt und

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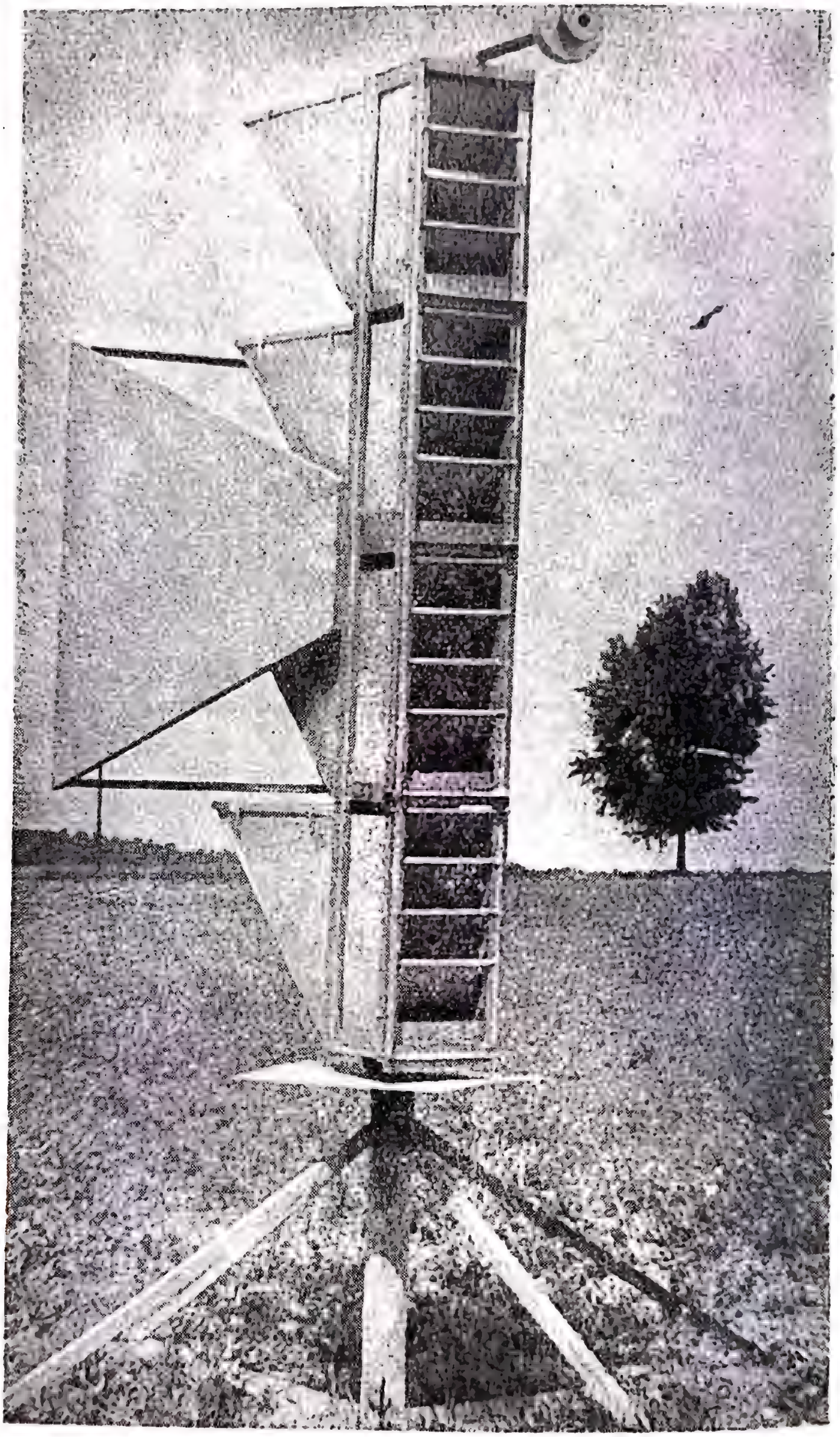

Abb. 1. Deflameter D-1

Anmerkung. De Basis des Deflameters wird beim Aufbau in den Boden eingegraben. Der unterste Auffangkasten befindet sich danach ca 10 cm über der Erdoberfläche.

auf verschiedene Höhen emporgewirbelt werden, aufzufangen. In gewissem Grade soll es auch dazu dienen, die Dynamik der aufgewehten Teilchen kennenzulernen. Der Bau dieses Gerätes, das die Konstrukteure „Deflameter D-2" benannt haben, ist folgender (Abb.1).

Den wichtigsten Teil des Deflameters bilden vier Auffangkästen, die drehbar an einer Achse angebracht sind. Die Öffnungen dieser Auffangkästen befinden sich auf einer Höhe von: 10—53 cm, 59—102 cm, 108—151 cm und 157—200 cm, Die Auffangkästen stellen sich, infolge der Windeinwirkung auf die Flügel des Gerätes selbsttätig zur Windrichtung ein. Sie sind an der dem Wind zugekehrten Seite mit vier Jalousieplättchen versehen, die schräg zur Windrichtung angebracht sind. An diesen Plättchen gleiten die Bodenteilchen abwärts und fallen in die Behälter hinein. Um ein besseres Auffangen der mit grosser Geschwindigkeit in den Behälter eindringenden Bodenteilchen zu erzielen, befindet sich auf jedem der vier Kastenböden eine Wanne, die vor dem Versuch mit destilliertem Wasser anzufüllen ist. Mit dichter Flanelle bespannte Rahmen schliessen diese Kästen von oben ab und verhindern ein Wiederauswehen der allerfeinsten Bodenteilchen. Die Rückwand der Behälter ist erweitert, wodurch die Geschwindigkeit des Luftstroms im gewissen Grade abgeschwächt und ein besseres Absetzen der Bodenteilchen ermöglicht wird. Um die aus Stoff ausgeführten Teile vor Wind und Niederschlägen zu schützen, ist jeder Kasten mit einem Dach versehen. Da der Oberbau des Gerätes in grösserem Masse als der vordere Teil belastet ist, wurde, um eine einseitige Überlastung und Überneigung des Gerätes zu verhüten, ein Gegen- und Ausgleichsgewicht angebracht.

Das Gerät unterlag bereits einigen, wenn auch nicht sehr wesentlichen Änderungen.

Die Arbeitsweise des Gerätes ist überaus einfach. Dank der seitlich angebrachten Flügel, stellt sich das Gerät selbsttätig zur Windrichtung ein. Die durch heftige Windstösse aufgewirbelten Sand- und Staubteilchen Fallen durch die Schlitze in den Kasten und sammeln sich auf dem Boden der mit Wasser gefüllten Behälter (Wannen) an. Diese sind abends herauszunehmen und zu entleeren, worauf die Deflate (mengenmässig) in 1 Liter-Gläsern gesammelt und zur laboratorischen Analyse weitergeleitet werden.

Neben dem Deflameter sind auch andere Geräte eingesetzt worden, vor allem ein Rhumbo- und ein Anemograph. Das Zusammenspiel und Zusammenwirken dieser (und auch anderer) Geräte, mit deren Hilfe ein Zyklus von regulären Messungen eingeleitet werden konnte, erlaubt es, ein klares Bild über die Erosionserscheinungen zu erhalten. Die erste „Deflameter-Station" wurde auf den Feldern des Versuchsgutes „Stary Dwór" angelegt. Ab 1961 befindet sich diese Deflameter-Station auf den Versuchsfeldern von „Jaroty".

Die Arbeitsweise des Deflameters beruht auf einem schichtweise stattfindenden, d.i. einem auf verschiedener Höhe gleichzeitig erfolgenden Auffangen von Bodenteilchen und zwar in solchen Mengen, die die mechanische Zusammensetzung wie auch die quantitative, chemische und mineralogische Bestimmung ermöglichen.

UNTERSUCHUNGSGELÄNDE UND METHODIK

Die Untersuchungen der Winderosion im Gelände wurden in den Jahren 1958—1960 auf leichten Sandböden des Versuchsgebietes „Stary Dwór" durchgeführt, in den Jahren 1960—1961 in Posorty, von 1961 bis zum heutigen Tage in Jaroty, wo sich ein zwei Hektar grosses Versuchsfeld des Institutes für Bodenkunde befindet. Das ganze Versuchsfeld ist in 2 Parzellen geteilt. Auf jeder der beiden Parzellen wurde ein Deflameter aufgestellt. Die Parzelle mit dem Deflameter D-1, ist mit Futtergemenge dauernd bewachsen. Die andere Parzelle mit dem Deflameter D-2, liegt brach. Der Boden wird lediglich von den Unkräutern gesäubert. Auf jedem der drei Versuchsfelder wurden bodenkundliche Forschungen durchgeführt: es wurden die morphologischen, physikalischen und chemischen Eigenschaften der Böden ermittelt und seit 1963 Untersuchungen über die Mesofauna eingeleitet. Auch wurden Untersuchungen hinsichtlich der Wasserdynamik (aktueller Wassergehalt) vorgenommen. Die in den Geräten abgezetzten Deflate wurden denselben laboratorischen Untersuchungen unterzogen, wie die Böden des Auswehungsgebietes. Die Korngrössenzusammenzetzungen wurden nach Mieczynski, Köhn und nur ausnahmsweise nach der Aerometermethode ermittelt, der Humusgehalt nach Tiurin und Iszczerekow-Rollow. Es wurden Gesammtanalysen (im $K_2Na_2(CO_3)_2$ Aufschluss) durchgeführt, ebenso mineralogische Analysen nach Novak und Pelišek (Novak, 1938; Pelišek 1934). Zusätzlich erfolgte eine mikroskopische Analyse nach Laszkiewicz (1957). Die chemischen, physikalischen und mineralogischen Eigenschaften der Böden sowie auch der Deflate wurden durch die Mitarbeiter des Institutes für Bodenkunde der Landw. Hochschule in Olsztyn: Mgr Mgr T. Kawecka, M. Lewicka, I. Sobina, A. Nożyński, T. Woclawek und M. Żurowicz ausgeführt. In diesem Beitrag wird lediglich ein Ausschnitt der durchgeführten Untersuchungen der Winderosion behandelt.

KURZE CHARAKTERISTIK DES UNTERSUCHUNGSGELÄNDES

Die Böden des untersuchten Auswehungsgebietes wurden als schwach ausgeprägte Podsole (2 Versuchsfelder) und eine podsolige Braunerde (1 Versuchsfeld) aus Sand (fluvioglazialer Herkunft) angesprochen. Diese stark durch Winderosion beeinflussten Böden kennzeichnet ein von 5—20 cm tiefer Ap-Horizont mit einem von 0,31% bis cca 1% variirenden Humusgehalt und einer Einzelkornstruktur. Die Reaktion dieser Böden schwankt zwischen pH_{KCl} 4,0—5,8. Diese Böden gehören grundsätzlich der VI. (nur stellenweise der V.) Bonitätsklasse an.

Das Gelände ist sanft hügelig; die Fläche der einzelnen Auswehungsgebiete schwankt zwischen 5—20 ha. Während der durchgeführten Untersuchungen (1958—1963) konnten ca 22 grössere Sandwehen notiert werden und zwar in März einmal, im April zwölfmal, im Mai achtmal, im Juni einmal und im August einmal. Die Windgeschwindigkeit schwankte von 4 m/s bis 17 m/s. Die am häufigsten notierte Geschwindigkeit des Win-

des betrug durchschnittlich 11—13 m/s. Die Windrichtungen waren meistenteils: SO, S, SW, WSW, seltener S, N, W.

Deflationserscheinungen konnten bereits bei einer aktuellen Bodenfeuchtigkeit (im-*Ap*-Horizont) von 0,83—6,2% beobachtet werden, zweimal sogar bei Regen (1,2—2,5 mm).

ERGEBNISSE

Das Ausmass der Winderosion lässt sich auf Grund der in den Behältern des Deflameters abgesetzten Menge und Grösse der Bodenteilchen bestimmen. Die Messungen des aktuellen Wassergehaltes im Boden des Auswehungsgebietes, während starker Winde, wiesen auf eine verhältnismässig schnelle Austrocknung des Bodens hin; so konnte man z.B. auf dem Versuchsfeld von „Stary Dwór" im Jahre 1958 ein Herabsinken des aktuellen Wassergehaltes im Ap-Horizont während vier Tage bis zu einer Tiefe von 6 cm von 11,4% (Volumen %) auf 0,85% beobachten. Ferner liess sich feststellen, dass die Deflation in unserem Versuchsgelände bei einer Bodenfeuchtigkeit (auf einer Tiefe von 0—5 cm) von 0,83 bis 6,2% stattfindet. Die Untersuchungen der Wasserdynamik in Sandböden, im Zusammenhang mit der Winderosion, bilden das Thema einer anderen Abhandlung. Allgemein kann behauptet werden, dass die Deflation in Sandgebieten von vielen Faktoren abhängig ist, unter denen die Bodenverhältnisse, die Windstärke und Richtung, die Temperatur, die Luftfeuchtigkeit der Bedeckungsgrad des Auswehungsgebietes mit Saaten und deren Entwicklungsstadium, sowie das Relief die Hauptrolle spielen. Mittels des Deflameters konnte bestätigt werden, dass die Stärke der Deflation im allgemeinen eine Resultierende vieler Faktoren ist. Einzelne stark hervortretende Faktoren üben meistenteils einen grossen Einfluss auf das Ausmass der Deflation aus, können aber durch andere, entgegenwirkende Faktoren bisweilen aufgehoben werden (Tabelle 1). Hervorzuheben wäre z.B. der Einfluss der Pflanzendecke, der die Deflation zu hemmen vermag. Das Deflameter D-1, auf der mit Haferwicken-Gemenge besäten Parzelle, hatte während der Deflation am 27—28. III.1961 eine etwa 22—1,5 mal geringere Deflationsmenge aufgefangen, als das Deflameter D-2 auf der umbesäten Parzelle.

Die Höhe der während der Stürme aufgewirbelten Sand- und Staubmassen ist erheblich und beträgt meistenteils einige Meter. Wenn man von den Deflationsmessungen während der Jahre 1958—1963 ausgeht, kann man behaupten, dass in den Standortsverhältnissen des untersuchten Geländes die Skeletteilchen des Bodens während des Sandwehens an der Oberfläche durch den Wind rollend vorwärtsgetrieben werden, wobei ein Teil von ihnen sprunghafte Bewegungen ausführt, eine Höhe von 10 cm jedoch nur ausnahmsweise erreicht. Der Grob- und Mittelsand wird auf eine Höhe bis cca 100 cm, emporgehoben. Bei besonders starker Deflation kann jedoch auch der Grob- und Mittelsand in die beiden höchsten Behälter gelangen.

Diese Fraktionen können während des Sandwehens besonders schädlich auf die noch zarten Pflanzen einwirken. Der Feinsand, wie auch die

Tabelle 1

Menge der während einiger „Sandstürme" in den Deflamstern D_1 und D_2 abgesetzten Deflats

Ort. Datum, Deflameter-Typ		Aktuelle Bodenfeuchtigkeit 0—5 cm Gewichts-%	Geschwindigkeit des Windes m/s	Überwiegende Windrichtung	Menge der Abgesetzten Deflate in g				Niederschläge in mm
					Behälter 1	Behälter 2	Behälter 3	Behälter 4	
					Höhe/über dem Boden/cm				
					10—53	59—102	108—151	157—200	
Stary Dwór 10.IV.1959	D_1	5,40	11,8	SW SE	7,70	0,58	0,55	0,40	0,0
Stary Dwór 29.IV.1959	D_1	2,80	11,9	SE	2,45	1,00	0,70	0,75	0,0
Stary Dwór 7.V.1958	D_1	4,20	8,0	WSW	193,00	8,51	2,36	2,59	0,7
Posorty 11.IV.1960	D_1	0,94	7—12	ESE S	42,98	4,70	3,62	2,57	1,2
Posorty 22.IV.1960	D_1	4,80	7—12	WNW NW	4,57	2,48	0,67	1,27	0,0
Posorty 29.IV.1960	D_1	4,90	12	N NE	69,87	8,60	1,90	2,52	2,5
Jaroty 27—28.III.1961	D_1	6,35	13	SE	9,7	5,52	3,19	5,58	0,0
Jaroty 27—28.III.1961	D_2	6,26	13	SE	216,25	46,18	15,25	7,99	0,0
Jaroty 24—25.IV.1961	D_1	3,13	6,3	E	18,3	17,32	—	3,58	0,0
Jaroty 24—25.IV.1961	D_2	4,05	6,3	E	257,10	10,23	6,43	4,15	0,0
Jaroty 11.IV.1963	D_1	1,42	12	E SE	12,3	13,99	4,00	3,12	0,0
Jaroty 11.IV.1963	D_2	1,92	12—17	E SE	154,7	33,36	21,68	14,80	0,0

übrigen Fraktionen, werden in der Hauptmasse meistenteils bis zu einer Höhe von mindestens 2 m hochgeweht. Der Feinsandgehalt ist in allen Behältern sehr hoch; sein prozentualer Anteil (in den höchst gelegenen Behältern) beträgt 15,5—75,4%, die Menge der Abgesetzten Staubfraktion in diesen Behältern bis 73%, unterliegt aber sehr hohen Schwankungen. Die abschlämmbaren Teilchen ($\phi < 0{,}02$ mm) setzen sich hauptsächlich in den zwei obersten Schubläden ab, aber auch hier lassen sich grosse Abweichungen feststellen. Die Staub- und Tonteilchen werden natürlich viel höher als 2 m emporgewirbelt, leider konnte dies mittels unserer Geräte nicht bestätigt werden. (Tab. 2).

Hieraus ergibt sich, dass die Menge der Bodenteilchen, wenn auch sehr unregelmässig, mit der Höhe, zunimmt. Hierbei spielt die Heftigkeit der einzelnen Windstösse und der Wirbelwinde, infolge derer die teils emporsteigenden, teils herabsinkenden Teilchen auf verschiedener Höhe in die Behälter gelangen, eine nicht unbedeutende Rolle. Die Verarmung des Ap-Horizontes an feinen Bodenteilchen konnte auch unmittelbar auf Grund der Schlämmanalyse bestätigt werden. Gegen Ende einer Deflationsperiode wurden Korngrössenzusammensetzungen des Bodens im Ap-Horizont festgestellt und zwar auf zwei Tiefen: 0—3 cm und 5—10 cm. Es erwies sich, dass die oberste 3 cm starke Bodenschicht, im Vergleich mit der tiefer gelegenen 3—9 mal mehr Skeletteilchen, 5 mal mehr Grobsand, 2—4 mal weniger Staubteilchen und durchschnittlich 7 mal weniger abschlämmbare Teilchen enthielt. Diese Verarmung an Feinteilchen im Ap-Horizont kann aber auch durch das Anwehen der gröberen Bodenteilchen verursacht worden sein.

Um den Gehalt an verschiedenen Mineralien sowohl in Boden als auch in den ausgewehten Bodenteilchen zu ermitteln, wurden Analysen mit Anwendung von Bromoform nach Novak und nach Pelišek vorgenommen (Tabelle 2). Die erhaltenen vier Fraktionen (Fraktion I- sp. Gw. $< 2{,}60$, Fraktion II- sp. Gw. 2,60—2,69, Fraktion III- sp. Gw. 2,69—2,80 und Fraktion IV- sp. Gw. $> 2{,}80$) wurden ausserdem noch mittels eines Polarisationsmikroskops auf den prozentuellen Gehalt der wichtigsten Mineralien geprüft. Durch Summierung der Fraktionen I+III+IV wurde der Gehalt an verwitterbaren Mineralien (vM) ermittelt, die in Sandböden die wertvollste Nährstoffreserve darstellen. Unter diesen Mineralien befindet sich: Kalifeldspat, Natron- und Kalkfeldspat, Chlorit, Epidot, Amphybole und andere Silikate.

Der Gehalt an diesen Mineralien beträgt in den Böden des Versuchsfeldes „Stary Dwór" im Ap-Horizont 10,8—14,6% in den ausgewehten Teilchen dagegen 12,2—24,8% wobei der höchste Gehalt an vM im dritten Behälter zu finden war. Die Böden des Versuchsfeldes Posorty enthielten lediglich 2,98% vM-Teilchen, wogegen die entsprechenden Deflate 7,2—7,9% dieser Mineralien aufwiesen. Die von der Schneedecke gesammelten Deflate enthielten lediglich 3,9% vM-Teilchen. Die höchste Mineralkraft wurde in den Sandböden von Jaroty festgestellt, mit einem Anteil von 10—23,9% vM-Teilchen. Demgegenüber enthielten die ausgewehten Fraktionen 27,6 bis ca 40% an verwitterbaren Mineralien. Auch in diesem Falle hat sich der grösste Anteil dieser Fraktionen in dem dritten Behälter (101—158 cm Höhe) abgesetzt.

Tabelle 2

Mechanische Zusammenzetzung und Humusgehalt des Bodens im Auswehgebiet und der Deflate

Ort, Datum	Bodenprofile, Deflate aus den Behältern der D-1, D-2 und von der Schneedecke (S)	Tiefe der Probeentnahme / Absetzungshöhe der Deflate cm	Ø der Bodenteilchen in mm										Methode	Humus nach Tiurin
			> 1	1—0,5	0,5—0,25	0,25—0,1	0,1—0,05	0,05—0,02	0,02—0,006	0,006—0,002	<0,002	<0,02		
			%											%
Stary Dwór 7.V.1958	I	5—15	1,53	10,00	23,80	48,60	14,57	0,60	—	—	—	2,43	Mieczyński	0,62
	D-1	10—53	—	0,62	18,10	74,75	2,73	0,73	—	—	—	3,07	Mieczyński	2,60
		59—102	—	1,90	7,45	22,98	64,45	0,27	—	—	—	2,95		2,76
		108—151	—	1,80	6,40	24,33	51,50	8,99	—	—	—	6,98		2,76
		157—200	—	—	0,51	15,47	73,03	5,47	—	—	—	5,52		1,76
Posorty 29.IV.1960	III	0—3	0,00	2,40	54,40	32,20	7,00	0,00	0,00	3,00	1,00	4,00	Cassagrande modif. Prószyński	—
		4—10	1,70	4,80	23,60	54,60	12,00	2,00	0,00	2,00	1,00	3,00		1,02
	S	Oberfläche des Schnees	0,00	1,20	14,60	57,20	16,00	6,00	0,00	3,00	2,00	5,00		1,74
Jaroty 27—28.III.1961	I	5—10	1,90	7,30	24,73	58,51	2,22	3,77	2,62	0,40	0,45	3,47	Mieczyński, Köhn	0,33
		40—45	1,22	4,54	23,26	67,51	1,93	1,59	0,66	0,05	0,40	1,11		—
		100—110	0,00	4,18	21,90	67,58	4,64	1,30	0,65	0,05	0,00	0,70		—
	D-1+D-2	10—53	0,00	1,00	14,71	69,36	13,22	1,21	0,50	0,00	0,00	0,50		0,18
		59—102	0,00	3,95	16,87	70,35	4,31	3,87	0,55	0,10	0,00	0,65		0,31
		108—151	0,00	1,78	6,43	65,16	20,11	5,57	0,40	0,40	0,15	0,95		1,05
		157—200	0,00	0,00	8,00	75,35	9,41	6,76	1,33	0,05	0,10	1,48		0,67
Jaroty 24.—25.IV.1961	D-1+D-2	10—53	0,00	5,01	33,71	53,05	4,74	2,79	0,50	0,00	0,20	0,70	Mieczyński, Köhn	0,18
		59—102	0,00	4,62	9,41	60,39	14,03	9,89	1,41	0,00	0,25	1,66		0,85
		108—151	0,00	2,07	7,77	65,55	14,90	8,05	0,96	0,25	0,45	1,66		1,26
		157—200	0,00	1,18	8,36	56,95	17,86	13,48	1,51	0,16	0,50	2,17		0,99

Ausser den Mineralteilchen werden aber auch Humusteilchen ausgeweht was ebenfalls aus den bisherigen Untersuchungen deutlich hervorgeht. (Tabelle 3). In den Böden des Versuchsfeldes Stary Dwór beträgt der durchschnittliche Humusgehalt 0,6%, in den ausgewehten Fraktionen dagegen 1,76—2,60%. In den Sandböden von Posorty wurde ca 1% Humus fetgestellt, in den Deflaten 1,74%, in den Böden um die Deflationsstation Jaroty herum lediglich 0,31—0,68%. Demgegenüber enthalten die Deflate 1,88% Humus.

Der höchste Humusgehalt konnte in den Deflaten auf einer Höhe von 108—151 cm (Behälter 3) nachgewiesen werden. Der Humusgehalt der im Behälter 1 abgesetzten Teilchen war bisweilen niedriger als der Humusge-

Tabelle 3

Einteilung der Minerale im Boden des Auswehgebietes und in den Deflaten in Gruppen nach dem spezifischen Gewicht /Fraktion 0,5—0,05 mm/ nach Novak-Pelíšek

Ort, Datum	Bodenprofile, Deflate aus den Behältern der D-1, D-2, und von der Schneedecke (S)	Tiefe der Probeentnahme / Absetzungshöhe der Deflate cm	Fraktionen der Minerale nach dem spez. Gewicht in % — Fraktion I > 2,60	II 2,60—2,69	III 2,69—2,80	IV > 2,80	Gehalt an leicht verwitternden Mineralien (I+II+IV)	$\frac{III}{I+II+IV}$
Stary Dwór 26—27.VIII 1959	I	0—1	10,39	89,18	0,10	0,33	10,82	8,24
		6—10	14,13	85,43	0,12	0,32	14,57	5,86
	D-1	10—53	9,25	87,60	2,49	0,46	12,20	7,18
		59—102	14,42	78,39	5,97	1,22	21,61	3,63
		108—151	13,16	75,62	10,15	1,07	24,38	3,10
		157—200	10,59	84,03	4,38	1,00	15,97	5,26
Posorty 29.IV.1960	III	4—10	2,31	97,02	0,33	0,34	2,98	32,56
	D-1	10—53	6,58	92,79	0,25	0,38	7,21	12,87
		59—102	6,73	92,08	0,52	0,67	7,92	11,63
	S	Oberfläche des Schnees	3,10	96,09	0,37	0,44	3,91	24,58
Jaroty 27.—28.III 1961	I	5—10	9,92	89,18	0,35	0,55	10,82	8,24
		40—50	4,09	94,98	0,19	0,74	5,02	18,92
		100—110	14,51	84,92	0,20	0,37	15,08	5,63
	D-1 + D-2	10—53	3,89	95,18	0,27	0,66	4,82	19,74
		59—102	4,35	94,55	0,27	0,83	5,45	17,34
		108—151	18,10	80,68	0,24	0,98	19,32	4,18
		157—200	16,30	82,67	0,36	0,67	17,33	4,77
Jaroty 24—25.IV 1961	D-1 + D-2	10—53	3,28	96,29	0,15	0,28	3,71	25,95
		59—102	13,01	86,09	0,15	0,75	13,91	6,23
		108—151	20,80	78,20	0,53	0,47	21,80	3,59
		157—200	14,00	84,49	0,20	1,31	15,51	5,45
Jaroty 11.IV.1963	$D_1 + D_2$	10—53	24,53	72,91	0,29	2,27	27,09	2,69
		59—102	39,12	59,15	0,32	1,41	40,85	1,44
		108—151	45,53	52,74	0,49	1,24	47,26	1,11
		157—200	37,98	59,98	0,22	1,81	40,01	1,50

halt der Böden. Die bei den Deflaten festgestellte Abnahme des spezifischen Gewichtes in der Reihenfolge von unten nach oben (Behälter 1 bis 2) ist mit dem Humusgehalt eng verbunden und verläuft ungefähr parallel. Das Auswehen des Humus bestätigen auch Humusbestimmungen, an der Oberfläche der Ackerkrume auf einer Tiefe von 0—3 cm und 5—15 cm ausgeführt. Der Humusgehalt in dem der Erosion unmittelbar nicht ausgesetzten unteren Teil der Ackerkrume enthielt manchmal mehr als das doppelte an Humus (0,62—0,83%), im Vergleich mit dem oberen Teil (0,23—0,40%).

Diese Ergebnisse weisen darauf hin, dass die schon ohnehin dürftigen Sandböden während der im Frühjahr einsetzenden heftigen Winde allmählich aber beständig ihrer wertvollsten Bestandteile beraubt werden.

Die aus den Böden der Verwehungsgebiete herausgewehten Mineral- und Humusteilchen werden in der Regel in Bodensenken und auf dem Grunde der Seen abgesetzt, was eine Anreicherung an allochtonen Bestandteilen zur Folge hat. Die bisherigen Versuchsergebnisse wurden auch durch chemische Analysen bestätigt (Tabelle 4). Es wurde festgestellt, dass die ausgewehten Bodenteilchen einen geringeren Gehalt an SiO_2 als die gewachsenen Böden enthalten, dagegen aber einen höheren Gehalt an wertvollen Pflanzennährstoffreserven wie: CaO, MgO, P_2O_5 und auch an R_2O_3 — aufweisen.

Die im Jahre 1963 begonnenen Forschungen bezüglich der Bodenfauna bestätigen, dass diese in Böden mit Wicken-Hafer-Gemenge bis zu einer Tiefe von 50 cm zahlreicher als in unbewirtschafteten durch Winderosion stark beeinflussten Böden anzutreffen ist. (Die biologischen Untersuchungen wurden durch Frau Mgr I. Mirowska ausgeführt.)

SCHLUSSFOLGERUNGEN

1. Der Deflameter D-2 hat sich als ein geignetes, obgleich nicht fehlerfreies, Gerät zur Untersuchung der Winderosion erwiesen.
2. Während der Winderosion lässt sich eine verhältnismässig schnelle Austrocknung des Ap-Horizontes in Sandböden beobachten.
3. Die Menge der aus den Böden herausgewehten Teilchen resultiert aus verschiedenen, zusammenwirkenden Faktoren, unter denen die Windstärke, die Bodenverhältnisse, das Relief des Geländes und die Pflanzendecke an erster Stelle stehen.
4. Die Hauptmasse der ausgewehten Bodenteilchen besteht aus Feinsand und der Staubfraktion. Das Bodenskelett wird nicht höher als bis ca 10 cm emporgehoben. Die Grob- und Mittelsandfraktion wird während stärkerer Windstösse bis ca 100 cm emporgewirbelt, vereinzelt aber auch viel höher. Der Anteil der abschlämmbaren Teilchen wächst in den Deflaten der Behälter 1, 2 und 3 an, sinkt aber etwas im Behälter 4; er ist in den zwei letzten Behältern der höchste. Der grösste Teil der Deflate, wie Feinsand, Staub und abschlämmbare Teilchen, wird aber weit über 2 m hoch emporgewirbelt.
5. Die ausgewehten Bodenteilchen sind im Vergleich mit den Böden (im Ap-Horizont) reicher an leicht verwitterbaren Mineralien (Kalifeldspat,

Tabelle 4

Chemische Zusammensetzung (Aufschluss in Na K(CO$_3$)$_2$

Ort, Datum	Bodenprofile, Deflate aus den Behältern der D-1, D-2 und von der Schneedecke (S)	Tiefe der Probeentnahme / Absetzungshöhe der Deflate cm	SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5
			%						
Posorty 29.IV.1960	III	4—10	93,341	4,493	3,870	0,603	0,152	0,186	0,002
	D-1	10—53	88,883	3,319	2,328	0,989	0,185	0,066	0,002
		59—102	82,513	7,351	6,331	1,020	0,450	0,231	Sp.
		108—151	82,741	9,099	7,710	1,342	0,627	0,389	0,047
		157—200	82,599	4,365	3,457	0,879	0,376	0,343	0,029
	S	Oberfläche des Schnees	91,742	5,249	4,617	0,615	0,127	0,142	0,017
Jaroty 27.—28.III 1961	II	5—15	92,693	3,482	—	—	0,219	0,181	0,066
		50—55	93,835	2,776	2,252	0,526	0,223	0,172	0,002
		145—150	85,720	9,352	6,645	2,674	0,344	0,555	0,033
	D-1 + D-2	10—53	92,263	3,922	3,027	0,879	0,025	0,163	0,016
		59—102	89,839	4,563	3,258	1,174	0,231	0,234	0,131
		108—151	89,202	5,574	3,955	1,493	0,244	0,318	0,126
		157—200	88,853	5,199	3,366	1,724	0,155	0,227	0,109

Natron-Kalk-Feldspat, Chlorit, Epidot, Amphibole und andere Silikate).

6. Die chemische Gesamtanalyse hat einen höheren Gehalt an CaO, MgO, P_2O_5 und R_2O_3 in den ausgewehten Teilchen erwiesen, als in den Böden des Auswehgebietes, dagegen einen niedrigeren Gehalt an SiO_2.

7. Die Winderosion verursacht allmählich ein Verarmen der Sandböden an leicht verwitterbaren Mineralien und an Humus (daher eine Verarmung an Pflanzennährstoffen), hat aber gleichzeitig eine relative Anreicherung von Quarzkörnern im Ap-Horizont zur Folge.

8. Die bodenschützende Wirkung der Pflanzendecke wurde während der durchgeführten Untersuchungen bestätigt.

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ZUSAMMENFASSUNG

Die mit Hilfe eines Gerätes eigener Konstruktion u. zwar des Deflameters D-2 in verschiedenen Höhen aufgefangenen, ausgewehten Bodenteilchen wurden eingehend untersucht. Es konnte festgestellt werden, dass die ausgewehten Teilchen reicher an leicht verwitternden Mineralien und organischer Substanz sind, grössere Mengen an CaO, P_2O_5 und K_2O, dagegen weniger SiO_2 enthalten als die Böden des Ausweggebietes.

SUMMARY

With the aid of an apparatus of our design, called "Deflameter D-2", the deflatienary material was minutely investigated at different heights. It was established that the deflationary material is richer in easily weatherable minerals and organic substances, containing greater, amounts of CaO, P_2O_5 and K_2O, but less SiO_2 than the soils of the wind-erosion area.

RÉSUMÉ

On a examiné les particules de sol soufflées, captées à de diverses hauteurs à l'aide d'un appareil de construction propre, denommé „Déflamètre D-2". On a pu constater, que les déflates sont plus riches en minéraux facilement altérables et en substances organique, qu'ils contiennent des quantités plus grandes de CaO, P_2O_5 et K_2O, et par contre moins de SiO_2 que les sols des terrains soumis à la déflation.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

EQUILIBRIUM OF SOIL CONSERVATION AND SOIL CULTIVATION

M. J. AMOR ASUNCION[1]

INTRODUCTION: OBJECT OF THE WORK

In 1870 Dokuchaiev conceived the soil as a natural body. This is the way it has been considered by Coffey (1912), Marbut (1921), Joffe (1949), Soil Survey Staff (1951, 1960), Buckman and Brady (1960) among others.

The soil is a natural body; its vertical anisotropism mentioned by Jenny (1941) and its tridimensional character in Soil Survey Staff (1951) have been taken into account in this work.

It was also considered that the cultivation of the soil, in relation to its requirements, entails two systems of different ways of handling depending on whether or not they respect the soil requirements. We shall designate those that respect the requirements with the general name of "good handling" reserving that of "bad handling" for the others. Both of them determine variations in the cultivated forms of the soils with relation to its virgin forms. The object of this work is to consider that variation, trying to explain its genetical meaning in connection with the equilibrium of the virgin soil, which we shall designate with the name of "Equilibrium of soil conservation".

VIRGIN AND CULTIVATED SOIL

We shall consider as elements for discussion the modifications that cultivation produces in the soil under bad and good handlings.

With relation to bad handling, table 1 indicates certain facts, some of which are inferred and others taken from a work by Amor Asunción and Oliveri (in press), in which studies were made about profiles of virgin forms[2]

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[2] It doesn't belong to a virgin form in the strict sense, but it is thus considered because it helps perfectly as a reference basis to understand the effect of cultivation upon the virgin soil.

— not plowed — and cultivated near each other, with equivalent slopes 4 (four per cent) from the same prairie soil situated in the Province of Entre-Rios, Argentina.

The said profiles were studied in the upper and lower parts of the virgin and cultivated slopes.

As the variations found fundamentally affected the horizon A of the upper part of the slope in table 1 facts corresponding to the mentioned horizon were considered, from which only those useful for discussion were taken. From their consideration, it appears that in Entre-Rios soil, the cultivation produced morphological and analytical variations.

Table 1

Characteristics of horizons a of virgin and cultivated profiles from a prairie soil of Entre-Rios province (Argentina)

Location: the upper part of the slope				
	Cultivated Profile Solum: 68 cm		Virgin Profile Solum: 95 cm	
Horizons	Ap1	Ap2	A11	A12
Thickness (cm)	8	7	10	30
Organic matter g%	4.84	4.08	6.37	4.26
pH	5.85	5.90	6.90	6.80
Availlable Phosphorus P mg%	1.00	vestiges	10.70	8.50
Nitrogen g%	0.31	0.24	0.34	0.26
Exchangeable bases me%	24.58	25.17	34.30	31.00

From the morphological view point, the cultivated form shows less thickness of the soil due essentially to horizon A reduction. In the analytical order, the cultivation has increased soil acidity and has determined a decrease in the contents of organic matter, nitrogen available phosphorus and exchangeable bases.

The most reduced thickness of horizon A of the cultivated form, in the upper part of the slope, affects likewise the soil in the transversal plan, as the observation made at different points of the land indicates.

Thus, the total contents in organic matter, nitrogen and available phosphorus in the whole soil, fundamentally determined by that existing in its A horizon, are still comparatively higher in the virgin form than the sole consideration of the analytical facts seem to indicate. Even where it would not show differences, the variations would be determined by morphology.

The modifications produced through cultivation in Entre-Rios soil have thus affected it in its tridimensional character.

Variations produced through cultivation, under bad handling, in a flat Missouri soil, are indicated in Jenny's work (1941), in which there are no morphological profile modifications.

The variations between virgin[1] and cultivated form, however, are revealed in the analytical comparative facts that indicate highly significative superficial modifications in the horizontal plan, connected to different soil properties, many of which are the same as those considered in Entre-Rios'soil.

Considering the produced modifications through cultivation in Missouri and Entrer-Rios'soils we see that the properties that vary do so unfavorably from the view-point if soil fertility when it is handled in a way that does not respect its requirements. In relation to the modifications produced through cultivation, under good handling, it has been taken into account a morphological element "epipedon plaggen" treated in Soil Survey Staff (1960) which indicates that the mentioned epipedon, is the product of a continuous and intense manuring.

If the organic matter applied is conveniently selected, it is possible to obtain dark "epipedones plaggen" rich in organic matter, increasing considerably the thickness of the superficial horizon with relation to the original soil, producing thus morphological modifications of the profile.

Analytical variations highly significative, without production of morphological modifications, under good handling, corresponding to a flat prairie soil from Ituzaingo, used for orchard, are shown in (table 2). Every figure shown is the average of 25 determinations corresponding to surface samples (0—25 cm. depth) taken from different places of the "virgin" and cultivated forms of the soil considering in each case, when the samples were taken, an extension of about 400 sq.m. being this the approximate area of the orchard. Before starting the orchard on that soil it was considered necessary to enrich it with organic matter and phosphorus.

For that, a manure with 2.30 per cent of P_2O_5 from dry substance) was used. 60.000 kg. of manure per hectare with 69.5 per cent humidity was applied, doses considered necessary to attend to the soil requirements and the intensity of the exploitation.

The first year it was used as an orchard and the second year another 30.000 kg. of manure per hectare with 60.5 per cent humidity and 2.55 per cent of P_2O_5 (from dry substance) was applied.

The analysed samples were taken three months after the last application. After the second application of manure, the soil was continually used as an orchard with yields higher than those obtained from a small surface of untreated land (table 2). The soil available phosphorus was determined in accordance with Peech (1947), and organic matter by the Walkey-Smolik method as indicated by Paulsen (1938). The cultivated soil through good handling, offers variations of the corresponding properties in the opposite sense to that noticed through bad handling; i.e. when the soil requirements are respected, the property variations are favorable from the fertility viewpoint. Besides, it is interesting to indicate that subsequently to the second year the addition of manure was continued on purpose in different occasions until a dosis of 100 kg. per square meter was completed in a sector of the

[1] We have called virgin that prairie soil, not plowed, indicated in Jenny's Work according the same consideration for the virgin form of Entre-Rios soil.

Table 1

Ituzaigo's Soil

Average from 25 determinations	Virgin Form	Cultivated Form
Organic matter g%	3.67	5.29
Available Phosphorus (P) mg %	2.63	17.71

orchard soil, and at the end of the 3rd. year it was noticed in that sector that the ground rised in comparison to the untreated soil and also an increase of the dark superficial horizon (formation of an epipedon plaggen) took place while that superintensive treatment did not prejudice the high yields of the orchard.

EQUILIBRIUM OF SOIL CONSERVATION

As in the discussion the variations produced by cultivation will be connected with the virgin soil equilibrium, some consideration will be made on same.

The Conservation Equilibrium through its dynamism balances the natural losses of the soil with equivalent natural profits.

Thus the Conservation Equilibrium assures the relative persistence of soil properties expression and consequently of its total integrity, within reasonable lapses so long as the natural conditions remain unaltered.

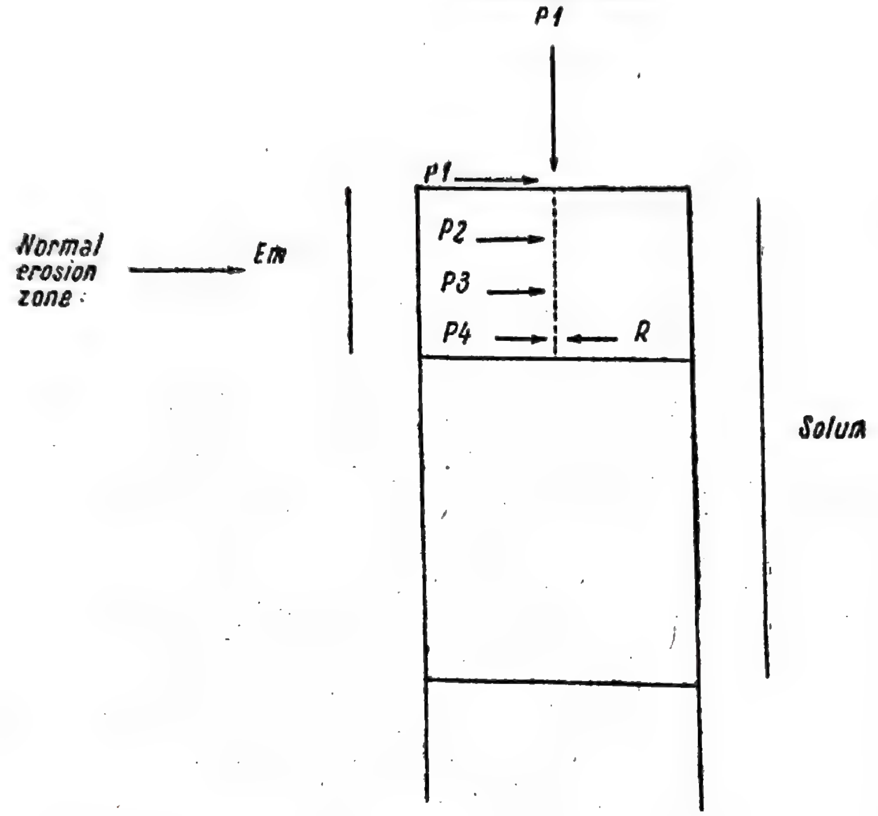
The Conservation Equilibrium defining property regulations, constitutes in itself, a general soil property. It assures a perfect material balance. The property variations produced through normal erosion or normal depletion are naturally compensated through processes of soil formation. Buckman and Brady (1960) and Soil Survey Staff (1951) refering to normal erosion, indicate the compensation of losses at the expense of the material subjacent to "solum".

That is possible because the formation processes act in all its thickness whereas normal erosion acts only in the upper part of the soil. Kohnke and Bertrand (1959) indicate that the soil erosion is a process of detachment and transportation emphasizing that the detachment has to precede transportation.

It is convenient to take into account that, initially, the normal erosion produces losses because, naturally, the resistance of soil, in the ambit of the superficial thickness where erosion acts, may have an inferior value to the power that — in a given moment — develops the erosive agent, which produces material separation from soil organization. If we consider the maximum power Pl the erosive agent may develop on that surface, it must be transmitted in depth, within an Em thickness in whose inferior limit the power will have an equal value to the resistance ($P_4 = R$), figure 1.

The P value (p1; p2; p3; p4) shall be softened in the vertical sense of the ambit of Em thickness. The resistence, instead, is considered with an equal R value in all that dimension, since in the small thickness where the

Fig. 1



$$(p1; p2; p3) > R$$

$$(p1; p2; p3) - R = d \text{ (positive)}$$

$$p4 = R$$

$$p4 - R = 0$$

normal erosion acts, the material properties are estimated vertically equivalent. Figure 1 illustrates somehow the above facts. The Em thickness could be compensated. We shall call it maximum thickness of loss, because beyond that value the processes of soil formation do not compensate the losses. Without suffering normal erosion, the soil might lose elements through other mechanisms, such as leaching.

This depletion would have normal character in natural conditions, i.e.it would compensate through action of formation processes.

In this way, the Conservation Equilibrium entails not only the persistance of the morphological integrity but also from the general properties of the soil.

DISCUSSION

The virgin variations considered above are due to the use of soil by man. All of them have a common genetical meaning that can be expressed as follows:

Soil cultivation modifies its properties and that variation is the result of Conservation Equilibrium displacement.

The morphological variation under bad handling, noticed in Entre-Rios steeped soil, was produced because cultivation reduced the R resistance of Equilibrium, which allowed the thickness where *d* is positive, surpass in magnitude the *Em* value (accelerated erosion), the losses being unable to be compensated through soil formation factors. The morphological variation in the opposite sense, positive modification or thickness profit, corresponding to Plaggen Epipedon, is explained because the vertical increase generated through addition of thickness, have appropriated resistance values to decide its persistance in the lapse and conditions determined by the material contribution of a good soil handling.

In Missouri's soil studied by Jenny, the profiles ressemblance virgin and cultivated, expressed by that author and the flat topography allows the rejection of accelerated erosion. However, the modifications produced through cultivation due to other mechanism cannot be compensated through formation processes. The soil conservation equilibrium is altered through bad handling and in the balance there is no equivalence between the profits and losses of the corresponding materials or soil elements.

The conservation equilibrium is also displaced in Ituzaingo's cultivated soil. Morphological variations were not noticed when the samples to be analized were taken; up to that moment the good handling corresponded to a reduced lapse (around 15 months). The highly significative analytical variations found of opposed sense to those produced through a bad handling, are due to the contribution that form part of the practices used and which modifies favorably the soil natural balance in relation to the determined properties.

CONCLUSIONS

The Conservation Equilibrium, as general property of virgin soil, allows to keep its integrity and its properties in natural conditions.

The use of the soil by man introduces new factors that modify the natural conditions displacing the conservation equilibrium.

This displacement may be diagnosed as soon as significative variations are detected among the values of some of the soil properties, in its virgin and cultivated form.

The sense or convenience of the variation with respect to fertility would depend upon a good or bad handling of the soil.

The Conservation Equilibrium displacement will correspond to an improvement of soil fertility conditions if its requirements are respected, which implies the possibility of concreting its potential aptitude. This is what happens in the intensive agriculture, that allows a continually high production.

The handling that does not respect the soil requirements cannot use to its maximum the natural productive aptitude of the virgin soil continuously, without producing a new and progressive, unfavorable equilibrium, expressed in different grades of accelerated depletion or accelerated erosion, as indicated in the examples that extensive agriculture offers.

The favourable results obtained when respecting soil requirements indicate that the agropecuarian exploitations must have a double purpose, that of respecting the human necessities (obtention of products) on one side and the proper attention to soil requirements on the other.

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SUMMARY

In this work *Equilibrium of soil conservation*, was designated as that which allows to keep the integrity and properties of its virgin form, in natural conditions. Variations produced in the soil through cultivation were considered.

Its meaning has been interpreted in connection with the Conservation Equilibrium.

It was established as a conclusion that the variations — due to cultivation of the soil — represent a Conservation Equilibrium displacement and that the sense of that displacement with relation to fertility, of great value for the production, depends on whether or not the requirements of the used soil are respected.

RÉSUMÉ

On a montré dans cette communication que l'équilibre de la conservation du sol, est ce qui permet de garder l'intégrité et les propriétés du sol dans leurs formes initiales, dans des conditions naturelles. On a pris en considération les variations produites dans le sol par la culture.

Le sens de ce fait a été formulé en relation avec son équilibre de conservation.

On a établi, en conclusion, que les variations dues à la culture du sol représentent un déplacement de l'équilibre de conservation et que le sens de ce déplacement en ce qui concerne sa relation avec la feritilité, d'importance majeure pour la production, dépend du fait que les exigences du sol soient ou non respectées.

ZUSAMMENFASSUNG

Un dieser Arbeit über das Gleichgewicht der Bodenerhaltung wurde alles jenes ausgeführt, was für die Bewahrung seiner Integrität und seiner Eigenschaften in der Urdorm unter natürlichen Bedingungen möglich ist.

Es wurden die durch Bearbeitung hervorgerufenen Bodenveränderungen in Betracht gezogen.

Ihr Sinn wurde im Zusammenhang mit dem Erhaltungsgleichgewicht gedeutet.

Als Schlußfolgerung ergab sich, daß die durch die Bearbeitung des Bodens hervorgerufenen Veränderungen eine Verschiebung im Erkaltungsgleichgewicht darstellen und dass der Sinn dieser Verschiebung was die Fruchtbarkeit anbelangt — dies ist von grosser Bedeutung für den Ertrag — von der Berücksichtigung der Nichtberücksichtigung der Erfordernisse des bearbeiteten Bodens abhängt.

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MINIMUM TILLAGE AS AN EROSION CONTROL PRACTICE [1]

R. L. COOK, A. E. ERICKSON [2]

The first objectives of tillage in the minds of humid region farmers is the coverage of manures, crop residues, and existing vegetation. The primary tillage tool is the moldboard plow. Buried trash is no longer a hindrance to precision planting and covered weeds are destroyed or are delayed sufficiently to allow a planted crop to become competitive.

A second and perhaps even more important objective of tillage is the loosening and crumbling of that fraction of the soil which is to become the root medium for the crop. The moldboard plow is the most important of all tillage tools for doing this job, for increasing the pore space of that fraction of the soil profile which becomes the habitat of most of the roots of the crop to be grown. In those soils where crop roots are nearly or entirely restricted to the plowed surface, one should seriously consider the advisability of deeper plowing so that plant roots may draw from a greater volume of soil.

"Plow-plant", one version of minimum tillage, is recognized by the U.S. Soil Conservation Service as an effective water management practice. Soil losses on certain experimental soils were reduced as much as 40 per cent where comparison was made with erosion losses from conventionally tilled land.

Experiments at the Michigan station, Cook et al. (1953) (1958), and elsewhere, Fanning and Brady (1963), Peterson et al. (1958), have shown that we should limit tillage operations to only those required to effect quick germination and good stands and result in satisfactory yields. After seeds germinate, loose soils furnish the best environment for roots and are most receptive and retentive of water. Other advantages were listed by the Michigan writers, Cook et al. (1958).

The purpose of this paper is to present results which prove the very important role played by minimum tillage as an erosion control practice.

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[1] Authorized for publication by the Director as Journal Article nr. 3335 of the Mich. Agr. Exp. Sta. E. Lansing. Michigan, U.S.A.

[2] Chairman and Professor, and Professor of Soil Science, Michigan State University, respectively.

EXPERIMENTAL

Two watersheds, each covering about two acres, on the Michigan State University farm, are so arranged and instrumented that runoff water and soil losses are measured and rainfall, amount and intensity, is recorded. The soil is Spinks sandy loam. Corn has been grown each year since 1959. One watershed is tilled in the manner commonly referred to as "plow-plant". It is moldboard plowed and immediately planted without subsequent tillage, in tractor wheel depressions. The wheels of the light tractor which pulls the two-row corn planter actually do a nice job of preparing the soil for the trailing corn planter. The second watershed is disced twice and harrowed twice between the moldboard plowing and planting operations. Planting immediately follows and is done during the same day and in the same manner as is that on the first watershed.

Rainfall, intensity and amount, and runoff and soil loss are recorded. Visual differences in surface soils, and soil movement over short distances due to micro-relief are recorded by photographs (see figures 1 and 2).

In 1962, the areas, respective to treatments were reversed. This precaution was taken to remove bias which may be due to slight differences in soil on the two areas.

RESULTS

During the three seasons 1960, 1961 and 1963, seven rainstorms caused measurable soil losses. Soil loss did not occur during 1962. Losses while the soil was under conventional tillage were much greater than while under minimum tillage. During an unusually intense storm in June of 1960, as shown in table 1, the respective losses were 32,000 and 4,000 pounds per acre, eight fold differences. The total precipitation during that June storm was not great, only

Table 1

The effect of tillage on runoff and eroison from continuous corn plots, 1960—1963

Date	Precipitation	Maximum intensity	Minimum tilled*		Conventionally tilled*	
			Runoff	Soil loss	Runoff	Soil loss
	inches		inches	lbs./A	inches	lbs./A
6/13/60	1.48	11.70	0.30	4000	1.04	32,000
6/7/61	1.03	3.09	0.002	0.39	0.17	1,600
6/13/61	0.66	4.80	0.044	260	0.07	930
8/19/61	2.28	7.20	0.75	910	0.88	1,000
1962			0.01	none	0.08	none
5/9,10/63	1.07	2.40	0.18	220	0.33	160
6/6/63	2.65	3.00	0.29	1400	0.66	2,900
6/8,9/63	1.63	3.84	none	none	0.05	390

* The tillage practice areas were reversed in 1962. In other words, the watershed which was minimum tilled in 1960 and 1961 was conventionally tilled in 1962 and 1963.

1.48 inches, but intensity was very high, 11.7 inches per hour. Again, in June of 1961, a storm relatively light in both inches of fall and intensity, caused a recordable amount of soil loss from the conventionally tilled area but only a trace from the other area. Another storm just seven days later, less in total fall but more intense, caused more soil loss on the minimum tilled area than did the one a week earlier but during this second storm there was less soil loss from the conventionally tilled plot. In other words, the losses from the two plots were approaching each other in amount, perhaps due to compaction caused by the first storm.

A continuation of this trend is evident from the data collected during the August storm of 1961. Runoff and soil loss were about equal from the two areas. Apparently the compaction caused by earlier storms had just about eliminated the soil saving effects of the "plow-plant" practice. Noteworthy also was the tendency toward less erosion in August than in June, a result no doubt of soil compaction and canopy protection offered by the corn leaves. Unfortunately so far as these data are concerned, there were no storms with sufficient intensity to cause runoff in 1962 (see table 2), the year when treatment was reversed on the two areas. Yields, however, were strongly in favor of minimum tillage during that year. In fact, as shown by the data in table 3, that was the only year when yield differences were great enough to be significant. The light rains during the growing season were able to enter the loose

Table 2

Seasonal rainfall and runoff and soil loss record during the years 1960 to 1963

Season*	Precipitation	Minimum tilled		Conventionally tilled	
		Runoff	Soil loss	Runoff	Soil loss
	inches	inches	lbs/A	inches	lbs/A
1960	12.7	31	4000	1.06	31,900
1961	13.5	87	1230	1.42	3,840
1962	9.6	01	0	08	0
1963	13.9	3	1624	1.12	3.693
4 season total	49.4	1.52	6854	3.68	39,433

* Season — May 1 to August 31.

Table 3

The efect of tillage on yields from continuous corn plots

Year	Minimum tilled	Conventionally tilled
1960	127.5	136.5
1961	101.9	105.1
1962*	80,4	55.6
1963	84.3	81.9

* The tillage practice area as reversea in 1962. In other words, the watershed which minimum was tilledi 1 1960-61 was conventionally tilled in 1962-63 and vice versa.

Fig. 1. Conventionally tilled watershed a few hours after the June 6, 1963 storm. Water overflowed the rows to leave a deposit of silt and fine sand. Note the evidence of extreme working of the soil by rainwater.

Fig. 2. Minimum tilled watershed a few hours after the June 6, 1963 storm. Water did not collect in sufficient volume to overflow the rows.

soil over the entire minimum tilled area instead of running to the lower levels as occured on the packed soil of the other area. Apparently minimum tillage is a water conservation practice as well as a control of erosion.

The 1963 data in table 1 show again the marked effect which tillage after moldboard plowing had on increasing runoff and soil loss. The totals for the year, runoff and soil loss, were more than doubled by the conventional tillage which followed. Yields were not increased by the "extra" tillage.

Persons connected with this project have frequently observed the soil conditions shown in figures 1 and 2, pictures taken on June 6, a few hours after the 2,65 inch rain of that morning. Corn plants were about six inches tall. Note that on the conventionally tilled area (fig. 1), water had flowed to the channel in the upper center of the picture and had overflowed the rows to deposit considerable silt and fine sand. The entire surface of the field showed much more evidence of the working effect of water than had occured on the minimum tilled plot shown in figure 2. This comparison has been observed in other locations.

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SUMMARY

Two fully instrumented watersheds on Spinks sandy loam soil have grown corn since 1959. One area received conventional tillage after moldboard plowing and before planting, the other was planted in tractor wheel marks without the conventional tillage. Treatments were reversed on the areas in 1962.

Total runoff from seven storms during a period of four years was much greater from land that had been tilled after plowing than from minimum tilled land. The same may be said about soil loss. In fact soil loss differences were relatively greater than runoff differences.

Intensity of rainfall was important so far as amount of soil loss was concerned and August runoff was less erosive than that which occured in June.

RÉSUMÉ

Deux versants d'un sol sableux-limoneux dotés avec toutes les installation nécessaires, ont été cultivés dès 1959, avec du maïs. L'une des superficies était cultivée d'une manière conventionnelle, aprés le labour effectué, avec une charrue à soc, et avant la plantation et pour l'autre, la plantation s'est faite dans les traces laissées par les roues du tracteur, sans culture conventionnelle après labour. En 1962, on a inversé les traitements sur les deux suppercifies.

La quantité d'eau d'écoulement accumulée durant sept orages, pendant 5 années, a été beaucoup plus grande sur les terrains cultivés après labour que sur les terrains cultivés au

minimum. On peut dire la même chose pour les pertes de sol. En fait, les différences de pertes de sol sont relativement plus grandes que les différences des eaux d'écoulement.

Dans le mesure dans laquelle elle concernait les pertes de sol, l'intensité des chutes de pluie a présenté de l'importance et l'eau d'écoulement du mois d'août a été moins érosive que celle qui s'est produite au mois de juin.

ZUSAMMENFASSUNG

Auf zwei vollausgerüsteten Wasserscheiden in sandigem Spinks-Lehmboden wurde seit 1959 Mais angebaut. Die eine Fläche wurde nach Scharpflugackern und vor der Bepflanzung konventionell bearbeitet, die andere wurde in Traktorenräderspuren ohne konventionelle Bearbeitung bepflanzt. Die Behandlungen wurden 1962 auf den Flächen umgekehrt vorgenommen.

Der Gesamtabfluss von sieben Gewittern während eines Zeitraumes von vier Jahren war viel grösser vom Boden, der nach vorhergehendem Ackern bearbeitet worden war als von einem minimal bearbeiteten Boden. Das selbe kann man über den Bodenverlust aussagen. Tatsächlich waren die Bodenverlustunterschiede verhältnismässig höher als die Abflussdifferenzen.

Die regenfallintensität war insofern bedeutend, als es die Menge des Bodenverlustes anbetraf und der August-Abfluß-koeffizient war weniger bodenabtragend als jener des Monats Juni.

DISCUSSION

IR. STAICU (Rumanian People's Republic), 1. What influence has the texture of soil on minimum tillage? 2. What is your opinion about decomposition of organic matter normally worked into the soil in comparison with the results of the minimum tillage?

R. L. COOK. 1. Minimum tillage will be satisfactory throughout the texture range. However, if clay content is high, great care must be taken to be sure the soil moisture content is correct for plowing. Very sandy soils may effectively be minimum tilled.

2. Minimum tillage may result in a more rapid depletion of organic matter because of more adequate aeration. Therefore more care must be taken to see that organic content is maintained.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

VI. 5

THE EFFECT OF CULTIVATION ON SOIL CONSERVATION

Z. FEKETE, A. TOTH[1]

INTRODUCTION

Numerous scientific rewiews dealing with erosional conditions in our country have been issued in the latter decades. Fekete (1952), Lang (1945), Stefanovits (1956), Lammel (1962), Toth (1959, 1960, 1961, 1962), Matyasovszky (1954) etc. have rendered accounts on erosional degree of erosion and possibilities of other control in various districts. The applications of these statements were only partly exploited, or were not carried out at all. We find the main reason was due to the farmers of small properties, who hindered the aplication of soil conservation. Some of the completed method fell out of date on account of development in technics. The modern huge farming form are given to up to date experiments on soil conservation and to the application of its results. The study of this problem is going on in Keszthely, on the grounds of the Agricultural College (Agrartudomanyi Föiskola) and at the farmers, cooperatives for the last five years. We are making a study of methods increasing soil productivity in various ways with soil conservation in mind. We have surveyed the effect of crop rotation on several cultivation forms (ploughing, sowing, etc). deep underground loosening and their co-operant influences on experimental plots by microparcels.

DESCRIPTION OF THE EXPERIMENTS

The soil conservation experiments and observations were carried out on the pseudogleyic brown forest soil in western Hungary and on the brown forest soil formed on loess at Kisgörbó. In experiments on crops in rotation we have methodically observered and examined: the quantity and intensity of precipitation, soil humidity, and the quantity of runoff water, and eroded soil. The growth, yield and variety of plant quality were studied. We should like to give a report on the role of deep-underground loosening by chisel upon whose results the co-operatives and state farms have achieved outstanding results (Városlód, Kisgörbó, Szentgyörgyvölgy etc.).

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EVALUATION OF THE RESULTS

First tests were made on pseudogleyic brown forest soils in Western Hungary. Here the water infiltration ability of the soil profil is very bad, because the structure of the top soil is bad and the clay content of the B horizon is large. Here is an accumulation of stagnant water in the B horizon in autumn, which causes a marbly gleyic horizon. Table 1 and 2 show the results of these experiments. These tables compare the data of yields and the percentage of erosion by soils. The year 1960 was better for observations on soil conservation in comparison with 1959. On 17 occasions there was more than 15 mm precipitation and in 1959 on 5 occasions 15 mm/hour rain intensity. In 1960 precipitation was above 10 mm on 21 occasions, on 11 occasions a 15 mm/hour rain intensity. Accordingly, the results of these two years showed a considerable difference and consequence.

The data of table 1 plainly show the differences in erosion with methods of various cultivations. The soil erosion was 9 times higher on a plain cultivated plot than on deep-loosened fields. In spite of the more frequent and more intensive rains, the erosion was only 7 times greater on the Sudan grass plot, than on plain cultivated plots. Although the deep-loosening proved its preventing effect on erosion, pedological investigations observations have definitely drawn our attention to the procedures of water-diverting mole drainage. The data on table 2 show that higher moisture is present the whole year round when deep-loosing is applied, but in late autumn not only we can remark higher soil humidity, but even water stagnation. This supersaturated state does not only hinders cultivation and sowing, but it even chokes the soil. On those types of soils, where in the soil profile we find intensive layers of water isolating accumulations horizon, subdrainage should be installed as deep-loosening is not sufficient by itself, but it is necessary, to make drainage too. Whilst on Western Hungarian pseudogleyic brown-forest soil and slopy brown forest soils cultivation is not fully solved by deep-loosing the brown forest soil of

Table 1

The formation of yield and soil erosion by various cultivating methodes on the pseudogleyic brown forest soils in western hungary

Crop	Cultivating methods					
	60 cm deep loosening + harrowing		ploughing + underground loosening + harrowing		only harrowing cultivation	
	yield q/acre	erosion m^3/acre	yield q/acre	erosion m^3/acre	yield q/acre	erosion m^3/acre
1	2	3	4	5	6	7
Indian-corn for silage	147	0.69	124	1.0	82	5.5
Sudan grass	29	1.25	35	4.2	23	8.5

Table 2

The fluctuations of soil moisture by various cultivating methods on pseudogleyic brown-forest soils in western Hungary

Date and depth of sampledrawing		cultivating methods		
		60 cm deep loose..ing + harrowing	ploughing + loose..ing + harrowing	only harrowing cultivation
1		2	3	4
April 30	0—10 cm	18.56	19.24	19.41
	20—30 cm	18.83	18.51	19.57
	40—50 cm	17.91	19.11	19.00
June 8	0—10 cm	17.63	18.00	17.00
	20—30 cm	18.17	17.60	17.00
	40—50 cm	18.00	17.15	16.20
November 24	0—10 cm	26.94	25.85	26.64
	20—30 cm	28.00	24.62	20.17
	40—50 cm	30.80	24.30	20.93

Kisgörbő's loess control is solved chiefly by this single operation into struggle against erosion. We are obliged to consider this as a divergent pedological attribution (see table 3 and 4).

Experiments on rotation combined with cultivation show that a quantity of water runoff from the plot is in close link with certain treatments. Irregular

Table 3

The water resistence of crumbs of the brown-forest-soil Kisgörbő's loess

Depth of soil sample drawing	percentage of the water-ressistant soil crumbs		
	> 1 mm	0,25—1 m	total
0—15 cm	31.3	13.5	44.8
15—20 cm	16.0	22.3	38.3
20—30 cm	4.8	35.7	40.5
30—45 cm	9.5	43.8	53.3
45—73 cm	3.2	35.0	38.2
73—90 cm	3.4	28.3	31.7
90 cm	15.2	15.2	30.4

Table 4

The water permeabylity and porosity of the brown-forest-soils of Kisgörbő's loess

Depth of drawn sample in cm	Specific density of soil	aparent bulk density	total P% porosity	capillar spore space %	water holding capacity P%	total volume %	total capacity P%	permeability ml/min
5—15	2.63	1.42	46.0	45.2	76.5	41.7	90.7	0.8
20—30	2.65	1.54	42.0	34.3	81.7	37.7	89.8	0.8
35—45	2.68	1.54	42.6	34.7	81.5	36,7	86.2	1.1
55—65	2.58	1.50	44.2	36.7	83.0	37.7	85.3	0.12
90—100	2.70	1.33	50.9	38.5	75.6	41.6	81.7	0.9

runoff is caused not only by precipitation intensity, but by the structure of the covering of the soil and not at least by cultivation.

The effect of the precipitation intensity depends mostly on the crumb consistance and the thin overlaying soil cover surface structure, the stability

Table 5

The composition of tested crops in rotation on the brown prest soils of Kisgörbő's loess

I. Clover with grass Clover with grass Potatoes Autumn cereals	II. Indian corn Spring cereals Sugar beet Indian corn for silage
III. Autumn cereals Autumn mixed crops for fodder Rape Autumn cereals	IV. Autumn mixed crops for fodder + second sowing Spring cereals over planted with red Clover Red Clover Potatoes

of the crumbs mostly show their effect when the ground is uncovered. When soil sludges soon, deep-loosening does not greatly increase the capacity of water bearing (see table 6, column 3). This fact allows us to conclude that deep underground loosening does not give the desired result, so in order to obtain effective results we are obliged to improve the soil structure too. In this case crumb, forming role of perennial plants, should be considered. The differences between various plants' erosion preventing effect are considerable because various coverings obtain the crumb ruining effect of precipitation. So Indian-corn suffers more by rain drop erosion than rape or cereals do (see table 6). In a general way it is a fact, that perennial plants' water runoff is much higher

Table 6

Erosion differences between crops in various cultivation on the brown-woodland soil of Kisgörbő's loess

Form of cultivation	Crop			
	Clover with grass	Indian Corn	Rape	Cereals
Growing on sloopy soil without deep loosening in contour cultivation	100	207	192	286
Growing on sloopy soil without deeploosening cultivation down the slope	100	216	188	278
Growing on sloopy soil with deep-loosening in contour cultivation	100	186	120	97
Growing on sloopy soil deep-loosening with cultivation down the slope	100	164	138	177

than by hoe-plants, especially at the beginning of rain, but the eroded soil quantity is the highest when uncovered Indian-corn is grown. The reciprocal relation between the effect of certain plants, and the effect of cultivation methods is not so striking as it is in the rotation system in general (table 7). If we consider contour farming with deep-loosening cultivation 100 then water runoff in the rotation as a whole, shows a visible proof of the direction in cultivation and deep underground loosening proves effective. The effect of deep loosening showed at its best in 1962, during the drought. There was no lack of water on the deep loosened fields, while on the fields where deep-loosening was not applied the plants suffered from drought. According to this, the yield was different.

Table 7

Total results of the percentage of run off water in percentage of the precipitation and percentage of caused erosion

Form of Cultivation	Rotation I		Rotation II		Rotation III		Rotation IV	
	1*	2**	1	2	1	2	1	2
Contour cult. with deep-loosening	100	100	100	100	100	100	100	100
Contour cult. without deep-loosening	134	117	223	189	103	108	178	164
Cultivation down the slope with deep-loosening	163	120	146	135	51	101	98	114
Cultivation down the slope without deep-loosening	170	132	200	161	128	112	217	151

* Runoff water in percentage of precipitation.
** Eroded soil percentage.

Our crop rotation sistems in this district are: 1) after 50 per cent well defending plants, badly defending potatoes and cereals; 2) only badly defending plants; 3) only autumn plants; 4) the rotation improved for soil conservation.

The effect of the quantity in water runoff, as we can see, was considerably different. This considerable difference was noticable all along the frame of crop rotation in percentage on eroded soil. Given conclusion on results, a close connection can be established between the deep loosing cultivation method and certain rotational plants' features. One would think, that a rotation of which 50% is grassy clover, should prove to be the best protection against erosion. It should be so if we take contour cultivation into consideration. In the growth of row crops, potatoes may spoil the value of rotation in the case of cultivation down the slope. Considerable soil erosion may be calculated when deep-underground loosing is not applied in contour cultivation. There is a favourable result in soil conservation when autumn crops are grown in rotation lastingly. In this case thes oil is always covered with plants and this

adds considerably to the preservation of drop-erosion developments. Here it seems to be proved, that if rain-drop destroying effect does not arise, so crop rotation without deep-loosening considerably reduces erosion, when plants are sowed in contour row (III rotation).

The effectivness of deep-underground loosening can be increased mainly if we apply it at the right time. Deep-loosening is not effective being actually even harmful in rain or mud. It is therefore absolutely necessary to make use of the most favourable weather. This is after the harvest-time, when there are no lasting rains, and the splitting effect of the chisel is best.

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SUMMARY

In Western Hungary, on pseudogleyic brown forest soils, the deep underground loosening by chisel gives good results in soil conservation only if it is supplemented by mole drainage. On the brown forest soil with clay illuviation west of lake Balaton, the 60 cm deep underground loosening combined with contour farming is very effective in soil conservation.

RÉSUMÉ

Dans l'ouest de la Hongrie, sur des sols bruns-forestiers à pseudogley, l'ameublissement profond par sous-solage, donne de bons résultats pour la conservation du sol seulement lorsqu'il est complété par le drainage taupe. Sur le sol forestier à illuvation d'argile, à l'ouest du lac Balaton, l'ameublissement profond de 60 cm, combiné à la culture suivant les courbes de niveau, est très efficace pour la conservation du sol.

ZUSAMMENFASSUNG

In Westungarn weist bei braunen pseudovergleyten Waldböden, die Untergrundlockerung gute Ergebnisse bei der Bodenerhaltung auf, aber nur dann wenn sie durch eine Maulwurfdränung ergänzt wird. Auf dem braunen Waldboden mit Tonilluvationen, westlich vom Balaton See, ist die Untergrundlockerung bis zu 60 cm Tiefe, mit Konturarbeiten nach Höhenlinien verbunden, für die Bodenkonservation sehr wirksam.

DISCUSSION

A. BECKEL (Deutsche Bundesrepublik). Wurden von Ihnen auch Versuche angelegt, in denen mit der Tieflockerung gleichzeitig Düngemittel (Ca, N, P, K) in den Unterboden eingebracht wurden?

Versuche in unserem Lande beweisen, dass die tiefe Einbringung einer mineralischen Volldüngung auf Pseudogleyen und Braunerde-Pseudogleyen den besten Effekt auf die Steigerung der Erträge und die Erhaltung der Auflockerung hat.

Z. FEKETE. Wir haben auch Forschungen, Mineraldünger kombiniert mit Tieflockerung, unternommen, aber diese sind noch nicht beendigt, und so kann ich noch keine Antwort erteilen.

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LES EFFETS DES TRAVAUX DU SOL ET DE DRAINAGE SUR L'EXCES D'HUMIDITÉ DANS UN SOL ARGILEUX, HOMOGÈNE SITUÉ EN PENTE

M. MOŢOC, S. TUDOR [1]

Les sols argileux situés en pente soulèvent une série de problèmes spéciaux en vue de la réduction de l'excès d'humidité du profil du sol dans les périodes pluvieuses et la conservation du sol à l'occasion des pluies torrentielles ou à la fonte des neiges.

Les nombreux ouvrages publiés les dernières années ont apporté des pré cisions importantes pour les sols à gley situés sur les terrains plans, en vue de la distance et la profondeur de l'emplacement des drains (Schwab, Kirkham et Johnson, 1957; G. S. Taylor, et Truman, 1957), l'influence du drainage sur la production agricole (Gardner, Bradford, et Hooker, 1952; Nesterova, 1963; Podvoiski, 1961; Schwab, Kirkham et Johnson, 1957), le rôle et la profondeur du labour au-dessus de la descente du niveau de l'eau et les modifications que les propriétés du sol subissent après les travaux de drainage (Andriauskaite, 1961; Podvoiski, 1961; Marita Yoshihiko, 1955).

Les sols à pseudogley situés en pente ont été peu étudiés (C. Haret et al., 1964) autant par rapport au drainage que par rapport à l'évitement de l'érosion. Pour apporter quelques contributions à résoudre ce probléme, on a organisé en 1961 des expériences sur terrain à la station d'horticulture Tg.-Jiu, de la région Oltenia.

I. MÉTHODE DE TRAVAIL

Les recherches ont été effectuées sur un versant à pente moyenne de 20%. Le sol d'un profil à eau stagnante est formé sur des marnes argileuses qui ont une épaisseur de plus de 10 m. Dans le tableau 1 on présente la teneur en argile, la quantité d'eau dans le sol à la suite des averses abondantes, aussitôt que le niveau de l'eau a baissé dans le profil au-dessous de 80 cm, et la quantité maxima d'eau dans le sol, déterminée dès que le niveau d'eau dans e profil s'est approché de la surface du sol (tableau 1).

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Tableau 1

Les propriétés physiques du sol

La profondeur de l'horizon cm	La teneur en argile < 0,002 mm %	L'humidité maxima après la retraite de l'eau en excès %		L'humidité maxima en présence de l'eau en excès %	
		sol en friche (pré-verger)	sol défoncé	sol en friche (pré-verger)	sol défoncé
0—20	59,3	33	42	45	53
20—50	65,3	36	45	42	50
50—80	60,5	36	41	40	44

Les horizons du sol ne sont pas différenciés comme texture à cause de l'argilosité élevée de la roche jusqu'à une grande profondeur.

Les précipitations moyennes annuelles totalisent 753 mm, dont 30% tombent aux mois d'avril, mai et juin et 17% en octobre et novembre, apportant un excès d'humidité dans le profil du sol. Les écoulements les plus puissants se produisent pourtant dans la période mai-août, lorsque tombent les plus fortes pluies torrentielles. Parmi les années quand on a fait les expériences, en 1961 les précipitations ont été au-dessus de la valeur normale, dans la période avril-juillet et novembre ; en 1962, en mars et avril et en 1963 toutes les précipitations ont été sous la valeur normale. Les conditions climatiques favorables permettent de cultiver des arbres fruitiers sur de grandes étendues. La réussite de la plantation de ces arbres est pourtant difficile étant donné qu'au printemps l'eau amassée dans les trous creusés pour la plantation est trop abondante, cause qui détermine leur perte. Le problème qui se pose pour ces sols est donc la réduction de l'excès d'humidité au printemps et aussi d'éviter l'érosion en été. L'expérience a eu lieu sur un terrain qui a été planté en 1960 avec des pommiers et a compris les variantes suivantes:

— des terrasses dont la largeur de la plateforme a été de 4 m et l'inclinaison transversale de 3—5% ; le sol ameubli sur toute la largeur de la plateforme jusqu'à une profondeur de 60 cm. Les talus des terrasses on été enherbés;

— terrain non terrassé qui a été maintenu en jachère par des labours répétés, à une profondeur de 15—20 cm;

— terrain en friche (pré-verger).

Chacune des variantes a compris sous variantes de drainage, à savoir: drain de pierre, drain de faisceau et sans drain. Les drains ont été installés à chaque arbre avant la plantation.

L'emplacement des variantes et sous-variantes a été fait d'après la méthode des blocs sous-divisés et a compris une surface de 5 ha. Le niveau de l'eau a été mesuré à l'aide de tubes perforés à la profondeur de 75 cm, emplacés à proximité du drain et à la moitié de la distance entre les drains.

II. RÉSULTATS OBTENUS

Pendant les années 1961, 1962, 1963, on a fait des recherches concernant le niveau de l'eau dans la profil du sol, l'écoulement à la surface et dans le sol, l'éau évacuée, la dynamique de l'humidité du sol après l'abaissement du niveau de l'eau sous la profondeur des racines et la croissance annuelle des arbres.

1. *La variation du niveau de l'eau dans le profil du sol*

Les déterminations ont été commencées en juillet 1961. Dans la figure 1 on constate que tous les ans l'eau paraît en excès dans le profil du sol, son niveau atteignant dans certains cas la surface du sol. L'excès d'humidité paraît régulièrement au mois de mars et se maintient jusqu'au mois de mai, et dans certaines années aux étés pluvieux (1961) il s'est maintenu aussi durant les mois de juillet ou même d'août. Rarement les pluies d'mois de novembre déterminent une hausse de l'eau le profil du sol.

La quantité de précipitations et le degré d'humidité antérieure du sol constituent les principaux facteurs qui déterminent la hausse du niveau de l'eau dans le profil du sol.

Le défoncement du sol jusqu'à une profondeur de 60 cm détermine un meilleur drainage du sol à une profondeur de 0—20 cm au début du printemps (1962—1963). Sur le sol en friche ou labouré à une profondeur de 15—20 cm, le niveau de l'eau atteint presque la surface. Dans la période mai — octobre le niveau de l'eau baisse très rapidement surtout sur les terrains en friche. Cette baisse est déterminée spécialement par l'évapotranspiration et par l'écoulement par le sol dans le sens de la pente. La marche des courbes indique, durant la période de végétation, une vitesse constante de la baisse du niveau de l'eau dans le sol, d'environ 1 cm en 24 heures au printemps, et en été de 2—2,5 cm en 24 heures dans un terrain labouré, et de 3—4 cm/24 heures dans la préverger.

Le niveau de l'eau est influencé aussi par la position sur le versant. Dans la figure 1 on peu constater que pendant la période pluvieuse, quand le niveau de l'eau se maintient élevé, il n'y a pas de différences entre le centre et le côte inférieur du versant, alors que dans la période de sécheresse qui suit, la baisse du niveau est beaucoup plus réduite dans la partie inférieure (0,8——1 cm en 24 heures par rapport à 2—2,5 cm/24 heures). Le retardement de la baisse du niveau de l'eau est dû en grande partie à l'alimentation supplémentaire avec l'eau provenant de l'écoulement par le sol.

Les modes de drainage (par faisceau ou pierre) ont joué un rôle réduit dans la baisse du niveau de l'eau. On a obtenu de petites différences dans les premières années en faveur du drainage en pierre. La rôle de la distance par rapport au drain a été établi par des tubes placés à 1 m de distance de l'axe du drain. Dans la figure 2 on présente la variation du niveau de l'eau au printemps de l'année 1962. On constate que les drains ont une grande influence

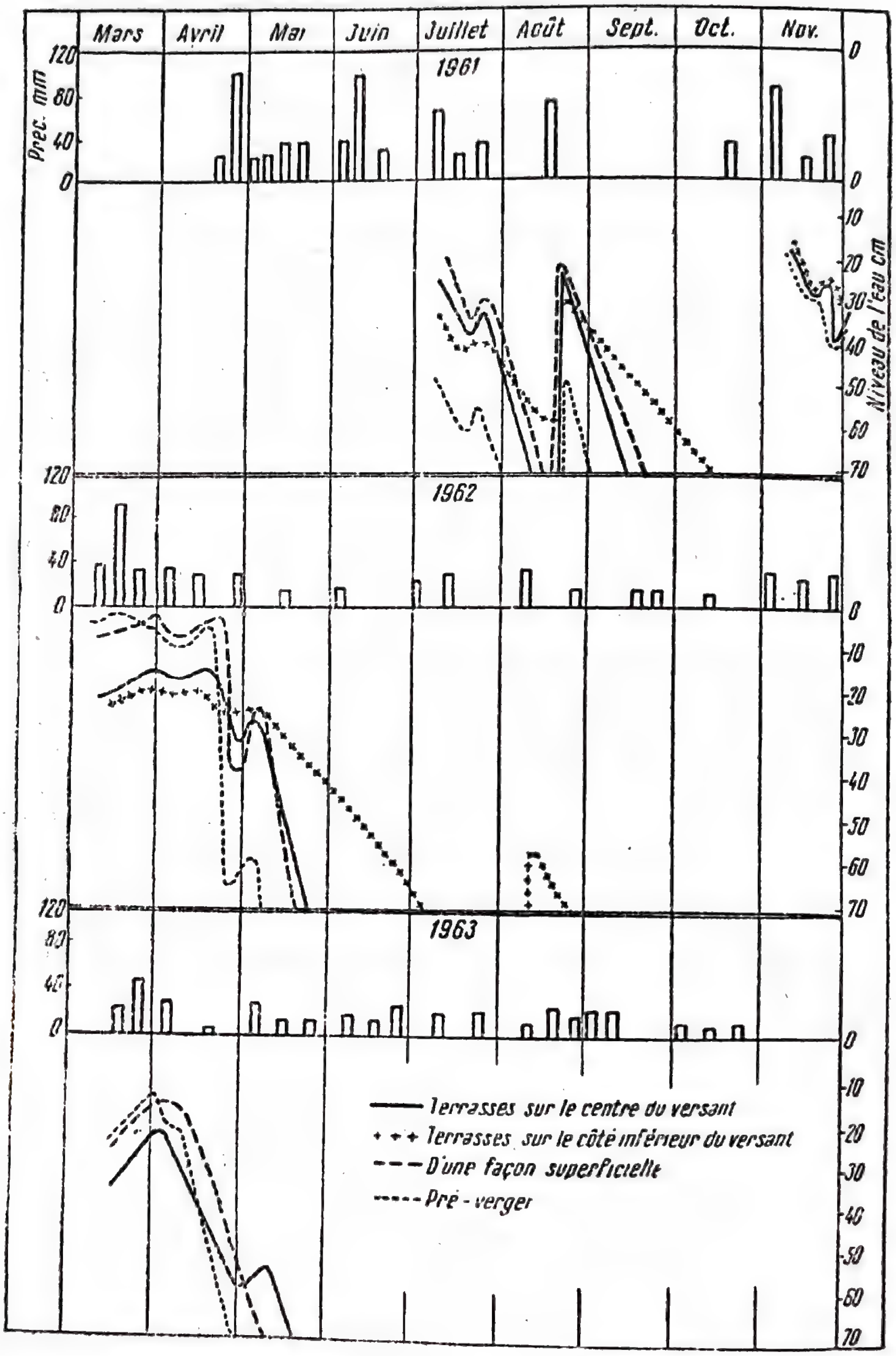

Fig. 1. Le niveau de l'eau en excès (1961—1963).

jusqu'à la distance de 2—3 m surtout durant la période d'évacuation de l'eau par les drains.

Pourtant le niveau de l'eau est influencé en grande mesure par le micro-reliéf qui est très varié sur les terrains en pente aux sols argileux.

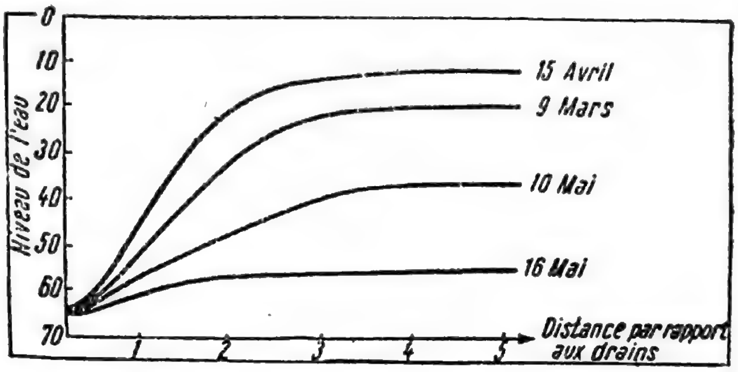

Fig. 2. Le niveau de l'eau en excès par rapport aux drains.

2. *Évacuation de l'eau par les drains, écoulement par le sol et de surface*

Dans le tableau 2 on présente la quantité d'eau évacuée par les drains en 24 heures.

On constate en premier lieu que les drains ont fonctionné chaque année mais durant un nombre restreint de jours. Les quantités d'eau évacuées sont

Tableau 2

Quantité d'eau évacuées par drains (1/24 heures)

Année	Mois	Jour	Terrasses sol défoncé		Terrain labouré		Pré-verger	
			Dr. P	Dr. F	Dr. P	Dr. F	Dr. P	Dr. F
1961	juillet	8, 9, 10	992	604	30	22	67	13
	août	17	600	252	16	7	15	10
1952	mars	3—6	147	118	300	281	862	764
1963	mars	28—31	552	550	360	288	384	288
	avril	1—3						

en rapport serré avec le niveau d'eau. Dans la saison de végétation les moindres quantités d'eau sont évacuées tandis que au début du printemps les quantités plus grandes. Si nous comptons que la surface desservie par un drain est de 20 m² (les parcelles en ce cas n'ont pas été isolées et il est possible que les drains aient évacué l'eau sur une plus grande surface) cela veut dire que les valeurs maxima du coefficient de drainage sont de 43—50 mm en 24 heures. L'écoulement par le sol dans le sens de la pente et celui de la surface ont été déter-

minés séparément, dans une parcelle specialement aménagée. Les données les plus concluantes ont été obtenus pendant l'été de l'année 1961 lorsqu'un grand nombre de pluies torrentielles ont provoqué des écoulements de surface. Ainsi, aprés une pluie légère de 50 mm, qui a humidifié le sol, suivie d'une pluie torrentielle de 45 mm, il y a eu à la surface un écoulement de 34 mm/m². L'écoulement par le sol, mesuré en aval de la parcelle a duré cinq jours et a été de 5 mm/m².

On a constaté que sur le terrain défoncé par bandes et terrassé l'écoulement par le sol dans le sens de la pente est empêché par les seuils non défoncés déterminant, dans leur voisinage, une hausse du niveau de l'eau jusqu'à la surface du sol. La sectionnement de ces seuils par des drains a favorisé l'évacuation de l'exces d'eau.

3. *Variation de l'humidité du sol dans les périodes de sécheresse*

Après la baisse du niveau de l'eau au-dessus de 75 cm on a observé la variation de la quantité d'eau dans le sol. Dans la figure 3 on constate que pendant les années de sécheresse 1962 et 1963, l'eau s'est conservée le mieux

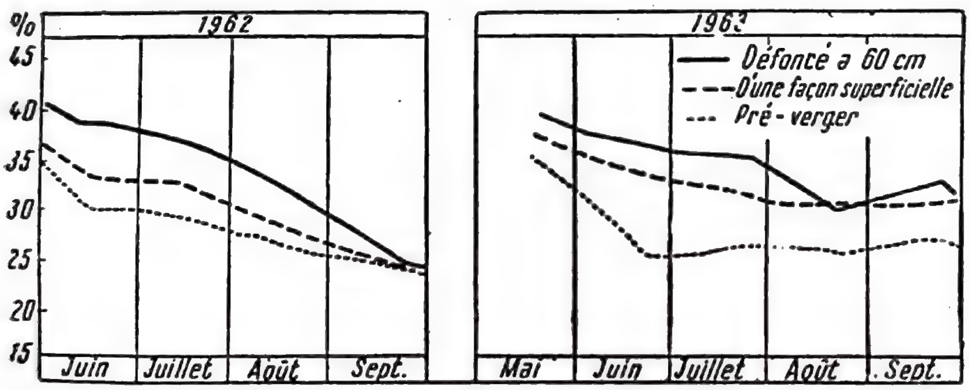

Fig. 3. La variation de l'humidité du sol.

dans les variantes au sol défoncé et ensuite dans le sol labouré. Les différences plus réduites entre le terrain défoncé et le terrain labouré, en 1963, s'expliquent par le fait qu'au cours de la troisième année l'ameublissement du sol a diminué dans la première variante.

4. *La croissance annuelle des arbres*

Le terrain a été planté durant l'automne de l'année 1960 avec le pommier Jonathan greffé sur E.M.IV. Dans le tableau 3 on présente les croissances annuelles des pousses.

Tous les ans le défoncement du terrain en terrasses a assuré une augmentation de la croissance de 32% par rapport à la façon superficielle et de 56% par rapport au pré-verger.

Tableau 3

Croissance de la pousse en cm

	1961				1962				1963				Croissances moy. par variante
	Dr. P	Dr. F	Sans dr.	Moy.	Dr. P.	Dr. F.	Sans. dr.	Moy.	Dr. P.	Dr. F	Sans dr.	Moy.	
Terrain défoncé et terassé	63	70	51	61	234	218	238	230	173	189	192	184	158
Terrain labouré	54	46	48	49	145	159	146	150	159	154	161	159	119
Pré-verger	52	48	45	48	135	128	119	127	138	117	132	129	101
Moyenne-par sous-variante	56	55	48	53	171	168	168	169	157	153	162	157	126

Différences limite pour 5%

	1961	1962	1963
Travaux du sol, val. moyennes	9	28,5	7,7
Drainage val. moyennes	7	non — significatif	
Drains divers sur le même travail	15,4	non — significatif	
Travaux différents du sol sous le même système de drainage	16,7	70	25,2

Le labourage habituel n'a donné une augmentation significative par rapport au pré-verger que la seconde et la troisiéme année après la plantation (18 et 23%).

Les drains n'ont assuré une augmentation de croissance significative que la première année de la plantation, quand l'excès d'humidité s'est manifesté durant la période de végétation. L'excès d'humidité dans le sol, avant le réveil de la végétation, n'a pas eu un effet négatif.

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RÉSUMÉ

Sur un sol argileux, homogène, situé sur un terrain ayant une pente de 20% on a observé durant 3 ans l'influence du terrassement, de l'exécution des travaux du sol à différentes profondeurs et celle du drainage sur le niveau de l'eau en excès dans le profil du sol, de l'écoulement à la surface et par le sol et la croissance des arbres fruitiers. L'ameublissement du sol en le défonçant jusqu'à une profondeur de 60 cm a assuré aux arbres une augmentation de croissance de 56% par rapport au pré-verger et de 32% par rapport au sol labouré à 15—20 cm. Le drainage n'a eu un effet positif en ce qui concerne l'abaissement du niveau de l'eau en excès que sur les sols défoncés à 60 cm., contribuant à l'évacuation de l'eau dont l'écoulement par le sol était empêché par les bandes de terrain non défoncées, qui constituaient le talus des terrasses. De même, on a obtenu des données concernant l'influence que la position sur le versant exerce sur le niveau de l'eau en excès.

SUMMARY

On a homogeneous, clay soil of a 20 per cent slope, the efects of terracing (bench-terraces), of soil cultivation at various depths and of drainage were investigated during three years, upon the level of water excess in the soil profile, surface — and soil runoff and growth of fruit-trees. The deep-loosening up to a depth of 60 cm determined a 56 per cent increase of growth at the trees in comparison with the meadoworchard and a 32 per cent increase in growth in comparison with the ground tilled at 15—20 cm. The drainage had no positive effect concerning the exceeding water level decrease, except on soils digged up to 60 cm, thus conducing to the evacuation of sub surface water, whose runoff by the soil was impeded by the untrenched ground, composing the terrace slope. Also data concerning the effect of the slope position on the exceeding water level were obtained.

ZUSAMMENFASSUNG

Auf einem homogenen, tonhaltigen Boden in einem Gelände mit 20%-iger Neigung wurde während drei Jahren der Einfluß der Terassenanlage, der Bodenbearbeitung in verschiedenen Tiefen und der Entwässerung auf dem Niveau des überschüssigen Wasser im Profil, des Oberflächenabflusses sowie des Abflusses durch den Boden und das Wachstum der Obstbäume beobachtet. Die Bodenauflockerung bis zu einer Tiefe von 60 cm hat den Bäumen eine Wachstumssteigerung von 56% im Verhältnis zum Wiesen-Obstgarten und von 32% im Verhältnis zu dem bis auf 15—20 cm bearbeiteten Boden gesichert. Die Entwässerung hatte einen positiven Einfluss auf das Niveau des überschüssigen Wassers nur auf den bei 60 cm Tiefe umbrochenen Boden und trug zur Entfernung jenes Wassers bei, dessen Abfluss durch den Boden durch die nicht umgebrochenen Geländestreifen, die die Böschung der Terrassen bildeten, verhindert war. Gleichfalls wurden Angaben betreffs des Einflusses der Abhanglage auf das Niveau des überflüssigen Wassers, erzielt.

ERODED SOILS OF THE FOREST-STEPPE ZONE IN THE EUROPEAN PART OF THE U.S.S.R., AGRONOMIC CHARACTERISTICS AND MEANS OF THEIR EFFICIENT UTILIZATION

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About 50 million hectares of land is subjected to water erosion in the U.S.S.R., about 10—11 million ha being medium and strongly eroded soil (Sobolev, 1961). As a result of the wrong use of soil slopes on some farms, water erosion is still taking place, enlarging the territory of eroded soils.

Soil protection against erosion, its control, reclamation and efficient utilization of eroded soils is of vital importance for the national-economic task, directed to the increase of food production for population and industrial raw material.

The progress of the Soviet soil erosion science, great achievements in soil and plant physics, chemistry and biology are extremely promising at present for the regulation of soil processes, aiming at the successful cultivation and efficient utilization of farm eroded soils.

The present paper gives an account of the results of long (1946—1963) comprehensive studies of morphological, physical, chemical, microbiological, cultural and economic characters of soil surface, differently affected by the processes of water erosion. The paper gives also the results of agrotechnical measures on prevention of erosion processes and the fertility rise of eroded soils.

Investigations were conducted in the Voronezh, Penza, Kursk and Poltava regions on 49 soils that differed in direction, shape, steepness and utilization of main arable slopes. Besides that, the staff of the soil expedition, the department of general farming and the laboratory of soil erosion of the Poltava Agricultural Institute summarised in 1957—1962 statistically significant data on soil survey of collective and state farms in the Poltava region on the territory of about 1 million hectares.

Principles, methods, the programme of investigations and main results of the work can be found in the author's publications (Cheremisinov, 1962 a, 1962 b, 1962 c).

The comparative genetical study of soil surface in connection with the relief of land and erosion processes has shown that eroded soils by their nature,

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agro-productive characteristics occupy their own place among other soils, they are characterized by the specific qualitative state and they differ from non-eroded soils of the same genetical type by a number of characters.

It has been found that eroded soils are characterized first of all by low capacity, lighter colour that is similar to the colour of the parental rock, by the tendency to crust formation, increased compaction of top soil and subsoil, strong soil pan, increased stickiness, viscosity, fluidity.

Summarized results of the analysis from 59 typical profiles of deep chernozem soil (table 1) poor in humus and differently eroded, show that eroded soils are poor in organic matter and have low content of humus in the upper horizons and sharp downward decrease along the profile.

Table 1

Humus distribution by soil horizons on eroded soils

Degree of soil erosion	Humus content in % in the depths:					Humus content in soil profile (t/ha)
	0—20 cm	35—50 cm	60—70 cm	115—135 cm	150—160 cm	
non-eroded	4.11	3.42	2.07	1.16	—	436
weakly eroded	3.29	3.08	2.34	0.96	—	386
medium eroded	2.44	1.96	1.37	0.23	—	243
strongly eroded	1.53	0.62	0.15	—	—	12
water-born	3.80	3.76	3.03	2.41	1.28	537

The dependence of the intensity of humus horizons and humus content in soil profile of chernozem soils with low amount of humus, are characterized by the positive correlation coefficients:

$$r \pm m_2 = 0.91 \pm 0.080,$$

where the number of samples $n = 360$.

Upper layers of eroded soils are poor in fractions of alphitite, including silty particles and rich with more coarse mechanical elements. The combination of humus horizon intensity with sand is expressed by correlation coefficient (r) $r \pm r\ m_2$, equal to -0.25 ± 0.037, and the relation between the intensity of humus horizon, and the content of silty fraction for 74 soil profiles is expressed by direct proportion:

$$r \pm m_2 = 0.28 \pm 0.042.$$

On large slopes and fast water streams all soil particles and even sandy fractions are rolling and passing along the slope. In this case the mechanical composition of surface horizon is enriched with silty and clay particles which result from the decomposition of the involved soil-forming, these particles being similar in their mechanical composition to the latter.

Organic matter and soil mechanical composition change on the relief mainly in connection with processes of water erosion, having essential effect on the formation of other agrobiological soil properties, first of all — physical and chemical ones.

As the data of table 2 show, eroded soils are characterized by little absorption capacity, increased saturation with bases by the higher bedding of carbonate horizon and by the increased pH of the saline extract.

Table 2

Agrochemical and phisico-chemical properties of the arable laier from eroded soils of the chernozem type (Average data for 13 administrative regions of the Poltavadistrict)

Indices	Soils				
	non-eroded	weakly eroded	medium eroded	strongly eroded	water-born
Number of soil profiles	173	87	62	24	14
Humus content (%)	4.07	3.57	2.84	2.16	3.45
Saline pH	6.67	6.73	6.94	7.50	6.50
Hydrolitic acidity mg/equiv. per 100 g of absolute dry soil	0.96	0.80	0.38	0.15	1.98
Adsorption capacity mg/equiv. per 100 g of absolute dry soil	32.17	30.53	28.56	23.90	26.37
Degree of bases saturation (%)	97.10	97.44	98.65	99.50	93.01

The structural characteristics of the arable layer may be judged by the mean values given in table 3, showing the strenght of the structure which decreases under the influence of soil erosion processes. In this case the relation between the quantitative increase of strong aggregates and decrease of soil erosion is expressed by the correlation coefficient:

$$r \pm m_2 = 0.61 \pm 0.064, \text{ where } n = 208.$$

Table 3

Phisical caracteristics of the upper (0—20 cm) horizon of eroded soils

Indices	Soils				
	non-eroded	weakly eroded	medium eroded	strongly eroded	water-born
Number of profiles	61	54	40	23	18
Bulk density (g/cm³)	1.18	1.21	1.27	1.30	1.23
Specific density (g/cm³)	2.44	2.46	2.48	2.54	2.54
Porosity (%)	51.7	50.8	48.9	48.9	49.8
Hygroscopic moisture (%)	4,93	4.87	4.40	3.71	4.8
Sum od waterstable soil aggregates 0,25 mm (%)	20.9	17.2	13.4	12.9	18.7

Eroded soils are characterized by low index of hygroscopic humidity, maximum hygroscopicity, maximum molecular and field water-holding capacity and water permeability, slight depth of soil infiltration after rainfalls and the increase of the coefficient of surface water run-off.

Table 4 demonstrates average content of mobile elements of plant nutrients in eroded soils. These data show that soil aggregates of the arable eroded layer contain less elements of plant nutrition as compared with non-eroded soils.

Table 4

Reserves of mobile forms of nutrients in eroded chernozem soils

Nutrients	Non-eroded	Weakly eroded	Medium eroded
	in the upper horizon	in the upper hotizon	in the upper hotrizon
Number of profiles	173	87	62
N	5.83	5.33	4.61
P_2O_5	10.74	9.05	6.54
a) solution in 0.5 n CH_3COOH	24.56	23.93	22.01
b) solution in 0.2 n HCl K_2O	10.60	10.33	8.31

The increase in the degree of soil erosion results in a gradual decrease of nutrient content. The relation between the degree of soil erosion and the content of mobile forms of nitrogen and potassium is better expressed with regard to phosphorus. Correlation coefficient between the capacity of humus horizon and the content of nutrients for the upper horizon of soil is expressed by the following formulae:

nitrogen: $r \pm m_2 + 0.60 \pm 0.037$;
potassium; $r \pm m_2 = + 0.37 \pm 0.026$;
phosphorus: soluble in 0.2 n HCl, $r \pm m_2 = + 0.27 \pm 0.036$;
phosphorus: soluble in 0.5 n CH_3COOH, $r \pm m_2 = + 0.32 \pm 0.043$.

The results of the study of biological activity of strong low-humus eroded chernozem soils of the Poltava region are given in table 5 according to the total amount of micro-organisms, cultivated on beef-extract agar and according to extracted carbonic acid.

Table 5

Microbiological activity of eroded soils
(Average data for soil layer 0—20 cm for 1959, 1960, 1961 seasons)

	Amount of bacteria (Millions per 1 g of soil)	Amount of extracted CO_2 (mg per 100g of soil)	Yield feeding units (centners per 1 ha)
Non-eroded	5.85	46.25	29.6
Weakly eroded	4.77	38.40	21.3
Medium eroded	2.07	17.93	12.8
Strongly eroded	1.42	11.47	8.5

Eroded soils are characterized by insufficient mobility and availability of moisture for plants, permanently low reserve of total and physiologically available water, resulting in limited rate of soil moisture and low moisture circulation, which is the main reason of low efficiency of these soils.

The obtained experimental data show that eroded soils result in the rise of yield losses, in decrease of production and money income per unit of land, in the rise of cost price and labour consumption per unit of production in decrease of daily and seasonal productiveness of farm engineering, in increase of fuel consumption, posibilities of comprehensive mechanization of farm production being limited.

Eroded soils result in lower yields of worse quality as compared with that on non-eroded soils, yields decreasing more in dry years than in rainy years. The plants, growing on eroded soils, have the increased transpiration coefficient, they are more subjected to the harmful action of drought in summer and to frosts in winter, they suffer a great deal from weeds, pests, diseases and many other unfavourable factors.

With the increase of soil erosion, activisation of erosion processes and relief complication, the negative indication of mentioned agronomical properties and characteristics of eroded soil are increased.

Experimental material of glasshouse, field and industrial tests, carried out for many years do prove the possibility of erosion prevention and changing eroded soils with unfavourable agronomical characteristics into highly productive arable lands.

Decisive agrotechnical measures in the struggle against soil erosion and the most important measures of cultivation and efficient use of eroded soils, are the following:

a) antierosion measures on the given territory, strip farming on arable slopes and soil conservating crop rotations;

b) anti-erosion system of soil cultivation;

c) anti-erosion system of fertilization;

d) anti-erosion and water regulating methods of winter agrotechnics (snow retention, regulation of snow and soil thawing);

e) growing the most yielding crops and varieties, selection of sowing material of high quality, correct determination of the quantity of plants per unit of land, the best methods of sowing, optimal depth of seed embedding and so on.

Comprehensive, timely, high-qualitative and differential application of these specific measures for eroded soils strictly combined with peculiarities of the mentioned soils, their present state, physical, chemical, biological characteristics, natural and economical conditions and physiological peculiarities of plants create such biological medium, in which cultivated crops can normally grow, develop, produce high yields, prevent the development of erosion processes and reestablish fertility of eroded lands. High yield is one of the most important factors of fertility, cultivation of eroded soils and prevention of erosion.

The most important method in the system of erosion control, cultivation and efficient utilization of eroded soils in conditions of rugged relief is expressed by means of upper runoff regulation.

The first and most important measure for reclamation and efficient utilization of eroded soils is the application of mineral and, first of all nitrogenous fertilizers.

The further tasks for the investigations of erosion processes, soil protection against erosion and efficient utilization of eroded soils, are the following:

1. The detailed and profound zonal studies of the development of erosion processes and eroded soils that are being formed under the influence of these processes, the use of the most modern methods of investigation and the providing of laboratories equipped with modern apparatus to the field;
2. Profound investigation and experimental evaluation of productive efficiency of the available anti-erosion and soil-cultivating measures and of those that are now under the progress;
3. Working out and practical application of regional anti-erosion farming system, and their improvement, taking into account the ever growing needs of agriculture and modern achievements in science and engineering;
4. Wide dissemination of the advanced practice and achievements of science.

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SUMMARY

The present paper presents experimental material concerning the genetical morphological, physical, chemical, agro-chemical and microbiological properties of the soil cover, carried out during 17 years (1946—1963); this cover was partly affected by erosion and partly by eolian deflation. Systems of agro-chemical measures for controlling soil erosion processes are also presented as well as cropping and agricultural utilization of eroded soils in the forest steppe zone of the European part of the U.S.S.R.

RÉSUMÉ

Dans ce rapport on expose le matériel expérimental concernant les propriétés génétiques, morphologiques, physiques, physico-chimiques, et microbiologiques de la couverture de sol étudié pendant une période de 17 and (1946—63). Cette couverture de sol fut attaquée par l'érosion et en partie par la déflation éolienne. De même, on expose des systèmes de mesures agrotechniques pour surveiller les processus de l'érosion, de même que la mise en culture et l'utilisation agricole des sols érodés de la steppe à forét de la partie européenne de l'U.R.S.S.

ZUSAMMENFASSUNG

Im vorliegenden Beitrag wird ein Versuchsmaterial über den genetisch-vergleichenden Komplex der morphologischen, physikalischen, physikalisch-chemischen, agrikulturchemischen, mikrobiologischen und produktionsiwrtschaftlichen Eigenschaften der Bodendecke dargelegt, der während einer Periode von 17 Jahren studiert wurde (1946—1963). Diese Bodendecke war durch Erosion und teilweise durch Abwehung angegriffen. Es wird gleichfalls das System der agrotechnischen Massnahmen dargelegt, um die Erosionsprozesse zu überwachen, desgleichen Bebauung und landwirtschaftliche Nutzung der erodierten Böden aus der Waldsteppe des europäischen Teiles der UdSSR.

DIE ERTRAGSFÄHIGKEIT STARK ERODIERTER PARABRAUNERDEN AUS LÖSS IM GEMÄSSIGTEN KLIMA

B. GROSSE [1]

Die Bodenkarte der Bundesrepublik Deutschland (Hollstein, 1963) zeigt auf dem weitaus grössten Teil der mit Löss bedeckten Flächen eine Parabrauerde, die im Profilaufbau mit dem "gray-brown podzolic soil" und „sol brun lessivé" vergleichbar ist.

Wenn auch die zur Entstehung dieses Bodentyps führenden Bedingungen noch nicht hinreichend geklärt sind, so zeichnet sich doch folgender Tatbestand eindeutig ab: Unter einem an Ton (Durchmesser < 2 μ) und Eisen verarmten Oberboden (A_3 — oder A_e — Horizont) von 40—60 cm Mächtigkeit folgt ein mit diesen Stoffen angereicherter Unterboden (B_t — Horizont), der erst in einer Tiefe von etwa 1—2 m in karbonathaltigen Löss übergeht.

Im Rahmen von Bodenkartierungen im südlichen Niedersachsen wurden bei diesen Lössböden stark verkürzte Bodenprofile als Folge der Bodenerossion durch Wasser angetroffen. Die seit Jahrtausenden in diesem Gebiet betriebene Ackerkultur hat bei dem dort meist herrschenden starken Gefälle den Abtrag ganzer Bodenhorizonte verursacht, sodass grossflächig B_t — oder C-Horizonte an der Oberfläche anstehen. Die auf den Flächen mit anstehendem B_t — Horizont angebauten Ackerfrüchte, besonders die Zuckerrüben, zeigten unter den sehr verschiedenen Niederschlagsmengen der drei Beobachtungsjahre einen auffallend guten Kulturzustand. Die dort ansässigen Landwirte gaben übereinstimmend an, dass die erodierten Hangböden aus Löss stets auffallend höhere Ernten an Zuckerrüben hervorbringen als die in ebener Lage vorkommenden Böden ohne Bodenabtrag (Grosse, 1963). Bei Getreide sollen derartige Ertragsunterschiede in Jahren mit normaler Witterung nicht beobachtet worden sein. Nur in nassen Jahren wurden auf den Hangböden wesentlich höhere Weizenernten erzielt als auf den nicht erodierten Böden der ebenen Lagen.

Durch die im Jahre 1963 durchgeführten Ertragsmessungen bei Zuckerrüben und Getreide sollten die Angaben der Praxis überprüft und den Ursachen der besseren Ertragsfähigkeit erodierter Parabraunerden mit Hilfe einiger Bodenanalysen nachgegangen werden.

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[1] Niedersächsisches Landesamt für Bodenforschung, Hannover, DEUTSCHE BUNDESREPUBLIK.

ALLGEMEINE ANGABEN ÜBER DAS UNTERSUCHUNGSGEBIET

Das Untersuchungsgebiet liegt auf den Lössflächen westlich des Leinetales, 20—30 km nördlich von Göttingen, etwa 130—150 m über dem Meeresspiegel. Geologisch handelt es sich um sehr mächtige Lössablagerungen der Weichseleiszeit über Jura-oder Keupertonen, auf denen sich eine im Unterboden leicht pseudovergleyte Parabraunerde entwickelt hat. Der ursprünglich karbonathaltige Löss ist in ebener Lage bis zu einer Tiefe von etwa 2 m entkalkt. Die jährliche Niederschlagssumme beträgt im vieljährigen Mittel 635—671 mm. Die Verteilung der Niederschläge der beiden für das Untersuchungsgebiet in Betracht kommenden Stationen ist aus Tabelle 1 zu ersehen:

Tabelle 1

Mittelwerte des Niederschlages (1891—1930)

Jan.	Feb.	März.	April	Mai	Juni	Juli	Aug.	Sept.	Okt.	Nov.	Dez.	Jährl.
Station Hillerse, Seehöhe 130 m												
52	41	42	46	46	62	75	68	52	54	43	54	635
Station Einbeck, Seehöhe 113 m												
57	44	42	46	54	62	85	70	54	54	48	55	671

Zum maritimen Klima gehörend, würden die Böden von Natur aus einen Eichen-Hainbuchenwald (Querceto-Carpinetum medioeuropaeum typicum) tragen. Zahlreiche bandkeramische Funde im Untersuchungsgebiet weisen auf eine dichte Besiedelung im Neolithikum hin. Die untersuchten Lössböden werden seit langer Zeit ackerbaulich genutzt und tragen heute eine Fruchtfolge von Zuckerrüben — Weizen — Gerste (Roggen).

VERSUCHSANORDNUNG

Für die im Jahre 1963 durchgeführten Pflanzenertragsmessungen wurden solche Ackerschläge ausgewählt, die bei gleicher Ackerfrucht, Bodenbearbeitung und Düngung nur durch die Tätigkeit der Bodenerosion bedingte Unterschiede im Profilaufbau aufwiesen. Es wurden jeweilig 5 Teilstücke von 1 qm Grösse auf nicht bzw. leicht erodierten = a und auf stark erodierten Flächen = b getrennt abgeerntet und die erzielten Erträge als Mittelwert berechnet.

Die Hangflächen zeigten unterschiedlich grosse Einzugsgebiete und Hangneigungen von 4—7%. Die Ackerschläge verliefen sowohl in südlicher als auch in nördlicher Hangrichtung. Die Aberntung wurde bei 5 Versuchsserien mit je 5 Getreide-Teilstücken und bei 6 Serien mit je 5 Zuckerrüben-Teilstücken, getrennt nach Korn und Stroh bzw. Rübe und Blatt, vorgenommen.

ERGEBNISSE

Die in Tabelle 2 dargestellten Ertragswerte bestätigen die in der Praxis beobachtete gute Ertragsfähigkeit der erodierten Lössböden. Mit einem durchschnittlichen Mehrertrag von etwa 10% Zuckerrüben und 15% Blattmasse weisen die Hangböden selbst in einem relativ trockenen Versuchsjahr (1963) einen beachtlichen Unterschied auf. In einem feuchten Jahr (1961) wurden die Ertragsunterschiede nicht durch Messungen überprüft, müssen aber dem Augenschein nach als wesentlich grösser veranschlagt werden, zumal auf den nicht erodierten Flächen auffallend viele Fehlstellen zu verzeichnen waren. Von den Getreidearten ist nur bei Weizen ein eindeutiger Mehrertrag von etwa 5% Körnern und 7% Stroh gegeben, während die Erträge bei Roggen etwa gleich sind und bei Gerste einen geringen Minderertrag auf den erodierten Flächen aufweisen.

Die in Tabelle 3 aufgeführten Mittelwerte der Bodenanalysen zeigen bei den stark erodierten Böden mit anstehendem B_t-Horizont gegenüber den nicht- bzw. leicht erodierten Böden vor allem einen um 50% höheren

Tabelle 2

Ertragsmessungen 1963 auf Flächen mit Parabraunerde aus Löss *

A. *Zuckerrüben*

Versuchsstück	Mittlerer Rübenertrag von *b* im Verhältnis zu *a*	Mittlerer Blattertrag von *b* im Verhältnis zu *a*
V	+20.9 %	+ 6.2 %
VI	+14.6 %	+29.4 %
IX	+ 9.[illegible] %	— 1.7 %
XII	+ 8.5%	— 2.1 %
XI	+ 3.3 %	+19.2 %
X	+ 2.8%	+38.6 %
Mittel von 6 Versuchsstücken	+10,0 %	+14,9%

B. *Getreide*

Versuchsstück	Mittlerer Körnerertrag von *b* im Verhältnis zu *a*	Mittlerer Strohertrag von *b* im Verhältnis zu *a*
Winterroggen X	+ 0.4 %	—14.5 %
Wintergerste I	— 1.7 %	+10.5 %
Wintergerste VII	— 3.3 %	— 3.6 %
Winterweizen IV	+ 4.7 %	+10.9 %
Winterweizen II	+ 5.7 %	+ 3.2 %

* 1qm — Versuchsstücke mit je 5 Parallelen:
a = nicht, bzw. leicht erodiert; *b* — stark erodiert.

Tongehalt (Durchmesser $< 3\ \mu$)[1], der eine höhere Wasser- und Sorptionskapazität zur Folge hat.

Schiller und E. Lengauer (1962) fanden bei der statistischen Auswertung von Feldversuchen mit Hafer, dass sich der Tongehalt eines Bodens nur auf den Körnerertrag positiv auswirkte, wobei das Optimum des Tongehaltes bei 24—25% lag.

Ein wesentlicher Faktor für die höheren Erträge auf den Böden mit anstehendem B_t-Horizont liegt offensichtlich in den sehr unterschiedlichen Gefügeeigenschaften beider Böden. In dem nicht erodierten Boden liegt ein Bröckel-Plattengefüge vor, welches wegen des hohen Schluffgehaltes nur eine geringe Stabilität besitzt und bei stärkerem Regen dichtgeschlämmt wird. Das Erosionsprofil weist dagegen ein bröckelig-schwach polyedrisches Gefüge auf, welches durch die verkittende Wirkung des Tones bzw. Ton-Humuskomplexes stabilisiert wird. Diese Gefügeeingenschaften bewirken, dass ein "B_t-Boden" das Niederschlagswasser schneller als ein "A_e-Boden" aufnehmen kann. Eine Eigenschaft, die sich gerade für die Wasserversorgung der Hangflächen in trockenen Jahren günstig auswirkt und ausserdem zur Herabsetzung der Erodierbarkeit beiträgt.

So fanden Lüken und Strebel[2] bei vorläufigen Durchlässigkeitsmessungen mit der Doppelringmethode (innerer Durchmesser = 35 cm, äusserer Durchmesser = 55 cm) für den stark erodierten Boden mit anstehendem B_t-Horizont nach 4 1/2 Stunden Versuchsdauer etwa die dreifache Infiltrationsrate wie für den schwach erodierten Boden mit anstehendem A_e-Horizont. Die Messungen wurden im Untersuchungsgebiet im Monat August 1963 mit jeweils 5 Doppelringen auf Äckern mit Getreidestoppeln vorgenommen.

Bei den Ergebnissen der Bodenanalysen fällt besonders auf, dass der Gehalt an organischer Substanz in den Krumen bei erodierten und nicht erodierten Böden fast gleich ist[3].

Da bei dem Bodenabtrag am Hang auch ein grosser Teil der organischen Substanz verloren geht, ist es verständlich, dass bisher bei den meisten Bodentypen in Erosionslage ein niedrigerer Gehalt an organischer Substanz festgestellt wurde, als in den nicht erodierten Böden (Gračanin, 1962). Wenn bei den anstehenden B_t-Horizonten aus Löss die Humusgehalte trotz des Abtrages verhältnismässig hoch liegen, so könnte eine vermehrte Erzeugung von Wurzelmassen den Humusspiegel erhöht und die erosionsbedingten Humusverluste teilweise ausgeglichen haben. Inwieweit die Möglichkeit einer katalytischen Einwirkung auf die Huminstoffbildung durch die im B_t-Horizont in grösserer Menge vorhandenen Eisenverbindungen (Scheffer, Meyer. Niederbunde, 1959) eine Rolle spielt, muss noch offen bleiben.

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[1] Der Unterschied zwischen dem Tongehalt im A_e-und B_t-Horizont beträgt im ungestörten Profil bis zu etwa 100%. Die durch Erosion an die Oberfläche gebrachten B-Horizonte sind manchmal tonärmer, weil an den Hängen stellenweise schluffreicheres Abschlämmaterial vorübergehend zur Ablagerung kommt (Zwischenablagerung).

[2] Unveröffentlichte Ergebnisse der Bundesanstalt für Bodenforschung Hannover.

[3] Die im B_t-Horizont der nicht erodierten Profile eingelagerte und eingeschlämmte Menge an organischer Substanz beträgt etwa 0.3—0.5%.

Tabelle 3

Ergebnisse der Bodenanalysen *

Korngrössenverteilung in % des Feinbodens					pH (KCl)	Org. Subst. %	C/N	mval/ 100g Boden		V-Wert %	(Dithio-nitlöslich) Fe_2O_3 %
Durchm. < 2	2—20	20—60	60—100	100—200 μ				T—Wert	S—Wert		
Versuchsstücke mit Zuckerrüben a) nicht, bzw. schwach erodiert, $n = 6$											
13,3	25,6	56,1	4,3	0,6	6,5	1,7	—	13,3	11,6	86	—
b) *stark erodiert*, $n = 6$											
20,2	24,4	49,3	4,8	0,6	6,7	1,7	—	16,5	15,1	91	—
Versuchsstücke mit Getreide, a) nicht, bzw. leicht erodiert, $n = 5$											
14,1	26,7	54,6	3,3	1,2	6,9	1,7	8,6	14,2	13,1	92	0,73
b) *stark erodiert*. $n = 5$											
21,3	26,4	48,7	2,7	0,7	7,0	1,5	8,4	16,6	15,5	94	1,07

*Angewandte Methoden der Bodenuntersuchungen***

Korngrössenanalyse: Zerstörung der organischen Substanz mit H_2O_2, Dispergierung mit $Na_4P_2O_7$; Trockensiebung und Pipettanalyse nach Köhn.

pH — Wert: 0,1 n KCL, Glaselektrode.

Organische Substanz: Nasse Verbrennung mit $K_2\ Cr_2\ O_7$.

Stickstoof: Kjeldahl — Aufschluss.

Austauschbare Kationen: Extraktion nach Mehlich mit 0,2 n $BaCl_2$-Triäthanolamin-Lösung.

Lösliches Eisen: (dithionitlöslich) nach Jackson.

* Mittelwerte des Oberbodens (0—25 cm) von je 6 bzw. 5 Versuchsstücken mit Parabraunerde aus Löss.

** Für die Durchführung der Analysen sei den Herren Dr. H. Fastabend, Dr. B. Mattiat, Hannover, vielmals gedankt.

Wenn nach den obigen Ausführungen ein günstiger Einfluss der Bodenerosion im gemässigten Klimabereich bei der Parabraunerde aus Löss festgestellt werden konnte, so soll keinesfalls der Bodenerosion das Wort geredet werden. Abgesehen von der Zerstörung des Bodens durch Erosionsrillen und -furchen bedeuten die hangabwärts verfrachteten wertvollen Humus- und Nährstoffmengen einen erheblichen Verlust, der schon allein eine Bekämpfung des Bodenabtrages rechtfertigt. Ausserdem muss verhindert werden, dass weniger günstige Lösschichten (*C*-Horizont) oder Schichten ungünstigen Gesteins durch weiteren Abtrag an die Oberfläche kommen.

Wenn die erodierten Parabraunerden aus Löss für den Ertrag anspruchsvoller Feldfrüchte günstige Voraussetzungen mitbringen, so wird dadurch gleichfalls zum Ausdruck gebracht, dass das Normalprofil der nicht erodierten Parabraunerde aus Löss nachteilige Eigenschaften aufweist. In der Tat mehren sich in der Praxis die Klagen, dass diese Böden in ebener Lage, besonders bei anhaltend feuchter Witterung, wegen der leichten Verschlämmbarkeit und des damit verbundenen ungünstigen Lufthaushaltes oft schlechte Ernten und sogar Missernten hervorbringen. Die hier angedeuteten Mängel und die

günstigen Ertragseigenschaften der erodierten Parabraunerden führten zu der Frage, ob nicht ein Tiefumbruch, wie er in Nordwestdeutschland so erfolgreich bei den Podsolböden vorgenommen wurde (Hollstein, 1960), auch bei den Parabraunerden aus Löss eine nachhaltige Verbesserung des Standortes herbeiführen könnte.

VORSCHLAG ZUR VERSUCHSWEISEN DURCHFÜHRUNG EINES TIEFUMBRUCHS BEI PARABRAUNERDEN AUS LÖSS

Der Gedanke einer Vermischung des im Unterboden befindlichen Lehms mit dem sandigen Oberboden bei Parabraunerden taucht in Deutschland wohl erstmalig in einer älteren Arbeit von Neugebauer (1945) auf. Allerdings handelt es sich dabei um Parabraunerden aus Grundmoräne mit einem hohen Steingehalt im Unterboden. Wenn der Vorschlag einer Vermischung des stark schluffhaltigen A_p-und A_e-Horizontes mit dem tonreichen B_t-Horizont von Parabraunerden aus Löss gemacht wird, so spricht für diesen Versuch die Beobachtung, dass der B_t-Horizont durch die Bodenfauna meist gut durchgearbeitet ist und viele Einlagerungen von Humus-und Losungsresten enthält. Es ist daran gedacht, durch eine Tiefkultur hauptsächlich folgende nachhaltige Veränderungen zu erreichen:

1) Herstellung eines homogenen und vertieften Wurzelraumes mit grösserer Wasserspeicherung;

2) Anreicherung des Tongehaltes im Oberboden um etwa 50% und dadurch Erhöhung der Wasser- und Sorptionskapazität;

3) Erzielung eines weniger zur Verschlämmung und zur Pflugsohlenbildung neigenden Gefüges;

4) Verringerung der Erosionsgefahr bei schwach geneigten Flächen.

Es ist geplant, eine Fläche mit einer im Unterboden schwach pseudovergleyten Parabraunerde aus Löss (Tongehalt im A-Horizont = 13% und im B_t-Horizont = 25%) bis zu einer Tiefe von 80—90 cm versuchsweise zu pflügen.

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ZUSAMMENFASSUNG

Ertragsmessungen haben die von der Praxis angegebene gute Ertragsfähigkeit stark erodierter Parabraunerden aus Löss bestätigt. So erbrachten im Jahre 1963 die Zuckerrüben im Mittel von 6 Versuchs-erien mit je 5 Parzellen von 1 qm Grösse etwa 10% Mehrerträge an Rüben (Spanne + 2,8 bis + 20,9%) und etwa 15% mehr Blattmasse (Spanne — 2,1 bis + 38,6%) als auf den nicht erodierten Böden. Bei Getreide war diese Tendenz nur bei Winterweizen gegeben, während Roggen keinen Unterschied und Gerste einen geringen Minderertrag auf den stark erodierten Böden zeigte. Die günstigen Eigenschaften der B_t—Horizonte konnten durch Analysenergebnisse belegt werden. Diese nur vorübergehend positive Auswirkung der Bodenerosion sollte keine Veranlassung geben, die Massnahmen gegen den Bodenabtrag zu unterlassen. Eine Vermischung der A_1 -und B_t-Horizonte mit Hilfe der Tiefkultur bei nicht erodierten Parabraunerden aus Löss wurde zur Diskussion gestellt.

SUMMARY

Production figures confirmed the good productivity, indicated by the practice, of severely eroded parabrown soils formed from loess. Sugar beet yielded during 1963, in the average of six trial eries with five plots each of 1 sq meter, about 10 per cent more beets (range + 2.8 up to + 20.9 per cent) and about 15 per cent green mass (range + 2,1 to 38,6 per cent) than on non eroded soils. This tendency appeared at cereals only for winter wheat, whereas rye did not present any difference and barley showed just a little decrease of yield on severely eroded soils. The favourable properties of the B_t-horizons could be confirmed by the results of analyses. These temporary positive effects of soil erosion should not be a reason to omit measures against soil erosion. The mixing-up of the A_1- and B_t Horizons by deep loosening on non eroded parabrown soils formed on loess was discussed.

RÉSUMÉ

Les mesurages de productivité ont confirmé la bonne capacité de production des sols le - sivés sur loess, tel qu'elle résulte de la pratique. Ainsi, en 1963 la betterave à sucre a donné en moyenne pour six séries d'expériences sur 5 parcelles de 1 m² un surplus de production d'environ 10% de betterave (limites + 2,8 à + 20,9%) et environ 15% plus de masse verte (limites — 2,1 à 38,6%) que sur les sols non érodés. Cette tendance s'est manifestée pour les céréales seulement chez le blé d'automne, tandis que le seigle n'a montré aucune différence et l'orge seulement une petite différence en moins sur les sols fortement érodés.

Les propriétés favorables de l'horizon B_t peuvent être confirmées grâce aux résultats des analyses. Ces effets positifs passagers de l'érosion du sol ne doivent pas induire à omettre les mesures à prendre contre l'érosion.

On a soumis à la discussion, pour les sols lessivés sur loess non-érodés le mélange des horizons A_e et B_t à l'aide du labour profond.

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ZONAL EROSION CONTROL OF INTENSIVELY CROPPED SOILS IN THE U.S.S.R.

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The intensification of Soviet agriculture, which involves more effective erosion control, has urged an overhauling of the zonal erosion-control practices now in use.

To-day in the U.S.S.R., much is being done to protect soils against water and wind erosion hazards and, if already eroded, to restore their fertility potential. The nature conservation laws in all the union republics stipulate that the conservation of soils, especially of arable ones, should be given priority. Those union republics which suffer from water and wind erosion have adopted specific instructions for dealing with it. And in general, soil conservation in the Soviet Union is fast becoming a matter of nation-wide concern. Because of its economic urgency, erosion control was taken up for discussion by the Lenin All-Union Academy of Agricultural Sciences convened early in June, 1963, expressly for that purpose. The session, which was also attended by practical farmers, endorsed recommendations for the control of water and wind erosion for each principal zone of the country according to the latest methods available.

Water and wind erosion hazards can be avoided only if erosion control becomes an integral component of intensive agriculture. Intensive agriculture should therefore include raising soil fertility, proper land management, and a host of other economic, agrotechnical, meadow-forest-meliorative as well as hydromeliorative practices all of which are designed to do away with erosion, practices adapted to the soil-climatic conditions of a particular zone or region. Similarly, choice is made of special machinery and equipment.

A vast country, such as ours, has a most craggy pattern of natural and climatic conditions. The processes of water and wind erosion take place in a widely varying soil-climatic and agro-economical environment. Nevertheless, it is possible to reduce the numerous erosion-control practices now preferred in no less numerous regions to one interzonal complex of practices and to recommend this complex for the major agricultural regions. Such interzonal practices may be summaized as follows:

a) repeated subsoil ploughing (without turning poorly fertile horizons over) in order to destroy the plough sole; raising soil absorption, moisture storage; balancing the surface flow of melt and rain water; building up a thick and improved arable layer;

b) in arid regions intensly attacked by wind erosion, chiselling with stubble left on the surface;

c) the following practices should be discarded (along slopes and along prevailing winds on plains): ploughing, cultivation, drillseeding, second square-pocket cultivation and hoeing; on steeper slopes, one should limit himself to cultivation across the slope;

d) in regions with a relief eroded by ravines and gullies and in those of bad erosion, contour and strip ploughing;

e) keeping a constant watch of arable microrelief (in order to balance the surface flow and avoid wash-out); filling and levelling rudimentary ravines;

f) occupied and green manured fallows instead of clean fallows;

g) buffer strips;

h) selection of crops and varieties which are adapted to eroded soils;

i) ploughing of steep slopes and light soils invariably accompanied by appropriate erosion control;

j) sodding and fixing of pre-gully and pre-ravine depressions in which melt and rain eater erodes the soil and initiates gullies and, in case of bad erosion, terracing of slopes;

k) fixing and afforestating of ravines and sands; sodding, afforestating, and taking under fruit of erosion-striken gully and mountain slopes, and the like lands; afforestation in this case is combined with building of appropriate hydraulic structures;

l) in steppes and forest-steppes, setting up of forest shelterbelts;

m) on erosion-striken land, through control of cattle-grazing, e.g. by means pasture-rotation.

The above inter-zonal practices for dealing with water and wind erosion, i.e. designed for all the agricultural regions, should be combined with intra-zonal practices, i.e., adapted to particular localities (table 1).

This combination makes a regional system of erosion control, which is to be further adapted to each particular farm and thus to be integrated into each particular local system of farming.

The areas in which water erosion prevails include the right banks of the Dnieper, Volga, Don, Dniester, Prut, Ob, Irtysh, and of their tributaries; such uplands as Central-Russian, Volga, Donets, Klin-Dmitrov, High Trans-Volga, and Obschy Syrt; such mountains (and their foothills) as the Crimea, Carpathians, Caucasus, and the Urals; such western regions as Moldavia, the Ukraine on the right bank of river Dnieper, the Central Chernozem

Region, North Caucasus, and the Black Sea Coast, in which erosion chiefly results from the heavy rains; such eastern regions as Volga, Ural, and Western Siberia, in which erosion chiefly results from the unbalanced melt-water discharge. The regions of predominant wind erosion are the Southern Ukraine, the North Caucasus, Bashkiria, the Trans-Volga region, Siberia and Kazakhstan. Both water and wind erosion affects a vast region in the U.S.S.R., which includes areas of dissected gully-ravine relief south of the following line: Balta-Kremenchug-Poltava-Kharkov-Balashov-Kuibyshev-Ufa-Novotroitsk-Magnitogorsk-Omsk. The most important in this zone are the Donets Basin, the Southern Ukraine, the Stavropol and Rostov regions, Krasnodar Border Region, Southern Central-Russian and Volga uplands, Bashkiria, and also the river basins of arid parts of Western Siberia and Northern Kazakhstan.

Irrigation erosion occurs on lands under irrigation of dissected relief in the European U.S.S.R. and Central Asia.

In working out zonal control we had to bear in mind that even within a single zone, e.g. the chernozem one, intra-zonal differentiation must prevail. Thus in the areas of Moldavia with little snow, where erosion results from rainstorms and from melt waters, erosion control should be confined to the rainy seasons. In Moldavia, special care should be taken of the soils under row crops since they are most vulnerable to storm erosion. Such practices as inter-row broken furrowing, deep loosening, and drainage furrowing (if the total rain-storm moisture cannot be retained in the field) should be preferred not only for Moldavia but for the right bank of the Dnieper as well.

From the left bank of the Dnieper (the Ukraine) towards the Volga region (Central Chernozem Belt), erosion is increasingly caused by the unbalanced melt-water discharge rather than by rain water. Therefore the storm erosion of soil under row crops is adequately controlled on gentle slopes by deep ploughing, decrustation, and by deep inter-row loosening. In these regions the protection of autumn- ploughed land from melt-water erosion gradually comes to the fore.

In North Caucasus, especially near river Kuban and in those parts of Moldavia which have a warm humid autumn, one will do well to practice undersowing, companion sowing, and postharvest sowing since these should furnish additional erosion control.

In the non-chernozem region with its derno-podzolic soils erosion, control varies with relief; in river basins, a gentle sloping relief prevails to enable a more extensive erosion control; in the regions with morainic- hilly topography, the slopes are abrupt to determine the nature of erosion (weak development of gullies) and hence the nature of its control.

At present, erosion control in the principal zones of the country is being intensively mechanised, i.e. zonal complexes of machinery and equipment are selected for the control of water and wind soil erosion.

Table 1

Zonal systems of erosion control

Practices recommended	Chernozem belt of the European U.S.S.R.						Chernozem belt of the Asiatic U.S.S.R.		Non-chernozem belt of the European and Asiatic U.S.S.R. including sod-podzolic soils and northern forest-steppe		Mountain regions of the U.S.S.R.		
	Moldavia	Ukrainian richt bank of river Dnieper	Ukrainian left bank of the Dnieper and Central Chernozem belt	Volga region	The north Caucasus, and especially, Kuban and Stavropol areas	chernozem and arid-chestnut a flat-country relief exposed to wind erosion	with a dissected relief (Siberia and Kazakhstan)	with a flatcountry relief exposed to wind erosion *	with a gull-ravine relief	with a morainic-hilly relief	subtropical areas **)	humid areas ***)	arid areas ****)
No ploughing, drill-seeding or second square-pocket cultivation for regions of acute wind erosion (on level sites along eroding winds)	—	—	e	—	r	r	—	r	—	—	—	—	—
Chiselling with stubble left on surface.	—	—	e	e	e	e	—	r	—	—	—	—	—
Inter-row temporary ridging after autumn sowing to retain melt water	e	r	r	r	r	r	r	r	—	—	e	e	e
Broken furrowing of dibbling	r	r	r	r	r	r	r	r	—	—	e	e	e

Inter-row deep cultivation broken furrowing, inter-row temporary ridging or hooing across the slope, sod-punching, drainage	r	r	e	—	e	—	—	—	e	e	e	e	e
Setting up of moisture-regulating shelter belts round gullies and ravines	r	r	r	r	r	r	r	r	—	—	—	—	e
Second cropping on post- and pre-harvest closely cropped fields	r	r	e	—	r	—	—	e	e	e	r	r	e
Formation of wind-stable crumby structure of loamy soil by appropriate tillage	—	—	—	—	—	e	—	e	—	—	—	—	—
Exclusive ring-rolling to prevent dust formation	—	—	—	r	r	r	e	r	—	—	—	—	—
Occupied fallows :	r	r	r	e	r	e	e	e	r	r	r	r	e
and slot fallows instend of clean fallows	—	—	—	r	r	r	r	r	—	—	—	—	—
Chiselling with stubble left on surface	—	—	—	e	e	r	e	e	—	—	—	—	—
Snow-retention, adjustment of snow melting and the like techniques	r	r	r	r	r	4	r	r	—	—	—	—	—
Snow-melting adjustment and the like melt-water retention techniques	—	—	—	—	—	—	—	—	r	e	—	—	—
Deep seeding	—	—	—	r	r	r	—	r	—	—	—	—	—
Row sowing of grain crops	—	—	—	e	e	e	—	e	—	—	—	—	—

Table 1 (continued)

Practices recommended	Chernozem belt of the European U.S.S.R.						Chernozem belt of the Asiatic U.S.S.R.		Non-chernozem belt of the european and Asiatic U.S.S.R. including sod-podzolic soils and northern forest-steppe		Mountain regions of the U.S.S.R		
	Moldavia	Ukrainian richt bank of river Dnieper	Ukrainian left bank of the Dnieper and Central Chernozem belt	Volga region	The north Caucasus, and especially, Kuban and Stavropol areas	chernozem and arid-chestnut a flat -country relief exposed to wind erosion	with a dissected relief (Siberia and Kazahkstan)	with a flat-country relief exposed to wind erosion *	with a gull-ravine relief	with a morainic -hilly relief	subtropical areas **	humid areas ***	arid areas ****
Deep furrow sowing of row crops such as maize melon, etc.	—	—	—	—	e	r	—	r	—	—	—	—	—
Reduction of areas where dust and fine aggregates are the source of black storms by setting up inter-spaces and forest belts													
Soil-liming	—	—	—	—	—	—	—	—	r	r	r	e	—
Leaving inter-spaces closely cropped with cereals	—	—	—	—	—	—	—	—	r	e	e	e	—

Special organisation of mountain farming which includes the control of inundations and mudflows	—	—	—	—	—	—	—	—	—	—	r	r	r
Tightly controlled cattle-grazing on Alpine and Sub Alpine meadows and in mountain forests coupled with pasture-rotation and strip-grazing	—	—	—	—	—	—	—	—	—	—	r	r	r
Deep ploughing (trenching)	—	—	—	—	—	—	—	—	—	—	r	—	—
Contour tea plantations	—	—	—	—	—	—	—	—	—	—	r	—	—
Use of soil-conserving crops, such as green manure	e	e	—	—	—	—	—	—	e	e	r	e	—
Furrow drainage	e	—	—	—	—	—	—	—	e	r	r	e	—
Narrow-row ploughing	—	—	—	—	—	—	—	—	e	r	—	r	—
Irrigation-erosion control	—	—	—	—	—	—	—	—	—	—	r	r	r
Erosion control while developing flood lands	r	r	r	r	r	r	r	r	r	r	—	—	—

* Nothern Kazakhstan; western Siberia, especially Kulunda; Krasnoyarsk Border Region.

** Georgia, Azerbaijan, Caucasian Black-Sea Const.

*** Northern and Western Caucasus, western partes of the Crimea, Carpathians, and of Kazakhstan.

**** Central Asia, Eastern Georgia and Azerbaijan, Eastern and Southern Caucasus, Daghestan and Eastern Crimea. r — recommended for actual production e — to be verified by experiments.

SUMMARY

The intensification of Soviet agriculture, and more effective erosion control that goes with it, have urged an overhauling of the existing zonal erosion-control practices. Although water and wind erosion develop under very different soil-climatic and agro-economical conditions, from the vast variety of practices one complex of measures emerges for all the principal agricultural regions.

For controlling water and wind erosion hazards the above complex is further extended to include intra-zonal methods current in particular localities (cf. the table). This combination forms a regional system of erosion control, which is to be further adapted to each particular farm and thus to be intergrated into each particular system of farming.

RÉSUMÉ

L'intensification de l'agriculture en U.R.S.S. et la lutte plus efficace contre l'érosion qui vont de pair, ont urgenté un nouvel examen des pratiques zonales existantes de la lutte contre l'érosion.

Quoique l'érosion par l'eau et celle éolienne se produisent dans des conditions pédoclimatiques et d'exploitation agricole très diverses, un ensemble de measures valables pour toutes, les régions agricoles principales, se détache de la grande varitété des pratiques.

Pour lutter contre le péril de l'érosion hydrique et éolienne, le complexe ci-dessus est étendu pour y comprendre les méthodes intra-zonales courantes dans certaines localités (v. le tableau). Cette combinaison constitue un système régional de lutte contre l'érosin,o qui doit être adapté à chaque ferme, en particulier, et, ainsi, intégré à chaque système particulier local agricol.

ZUSAMMENFASSUNG

Die Intensivierung der sowjetischen Landwirtschaft und eine wirksame Erosionsbekämpfung, die damit verknüpft ist, haben die Überprüfung der vorhandenen Bekämpfungsverfahren gegen die zonale Erosion beschleunigt. Obwohl Wasser -und Winderosion sich unter sehr unterschiedlichen pedoklimatischen und Landwirtchaftsverhältnissen entwickeln, tritt aus der grossen Mannigfaltigkeit der Verfahren ein Massnahmenkomplex hervor, der für alle landwirtschaftlichen Hauptgebiete gilt.

Um gegen die Gefahr der Wasser -und Winderosion anzukämpfen, wurde der obgenannte Komplex weiter ausgedehnt, um gleichfals die intra-zonalen Methoden einzuschliessen, die in einzelnen Ortschaften üblich sin (s. Tabelle). Diese Verschmelzung stellt ein regionales System der Erosionsbekämpfurg dar, welches dann weiter jeder einzelnen Wirtschaft anzupassen, und somit in jedes einzelne lokale Landwirtschaftsystem einzugliedern ist.

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VI. 10

SOIL EROSION AND MUD-FLOWS COMBAT IN THE MOUNTAIN AREAS OF THE SOVIET UNION

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Almost a third of the entire territory of the Soviet Union is occupied by mountains. In a number of places the ridges rise to an altitude of 3,000—5,000 metres. They are deeply gullied and marked by a considerable depth of the local erosion bases, which is one of the responsible factors for the steepness of the slopes.

Heavy precipitation and the soils, which are easily washed out by the rain, account for the heavy surface runoff and soil erosion, which is much more rapid and intense than in the lowlands. Heavy precipitations and often rapid thawing of the snow, coupled with rain, (plus the relief conditions in the mountains which are badly gullied and eroded) may be the cause of destructive mud-flows.

One of important factors in soil erosion and the formation of mud-flows in the mountain regions of the U.S.S.R. is the irrational utilization of the surfaces except physical-geographical conditions. This includes heavy felling of the mountain forests, chaotic grazing and ploughing of steep slopes.

Excessive surface runoff from denudated areas may be brought about not only by heavy rainfall, but also by rapid thawing of the snow in early spring. The heavy loss of water through surface runoff aggravates the water regime of the rivers which are fed by snow and especially those which are fed by snow and rains. These factors reduce the irrigation capacity of the rivers, necessitating large-scale irrigation and melioration work.

The loss of fertility and sharp worsening of the water and physical properties of the moderately eroded soils cut down crop yields to about a half whereas in soils that had been strongly eroded, the yields may be 3—4 times less than on non-affected soils.

In the deeply gullied mountain surface, runoff easily develops into erosion. The mountains slopes that have strongly eroded are practically lost for agriculture.

Research data indicates to the existence of vast areas of eroded soils in the mountain regions of the Soviet Union.

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Mud-flows often occur in Central Asia, the south of Kazakhstan, the Caucasus and the Trans-Caucasus. Of late, attention has been drawn to the mud-flows occuring in the Carpathians, the Crimea, the eastern regions of Kazakhstan, the Sayano-Baikal mountain region and even in the sub-tropical regions of Georgia.

One of the characteristic features of the mud-flows is their suddenness and short duration. They carry down the mountains an enormous amount of soil particles, shingle, rock and sometimes even large boulders. The record amount of matter (about 3,000,000 m^3) was brought down by a 4-hour mud-flow along the Malaya-Almaatinka river (in the Zaali Alatau) back in 1921. Another mud-flow in Azerbaidjan (Kishchai) brought down a boulder of 127 m^3.

The most frequent occurence in the mountains of the Soviet Union is a mud-flow comprising a considerable amount of solid runoff carried by water. Much rarer (in Georgia and Azerbaidjan) are mud-flows carrying liquified mud or mud and rock.

The mud-flows are a dangerous hazard to industrial enterprises, hydro-engineering units, railways and highways and sometimes even big inhabited points. They fill water reservoirs, kill people and cattle. When reaching fields, orchards or vineyards, the mud-flows cover them with rock, shingle and silt.

The tremendous losses inflicted by mud-flows were the main reason why mud-flow combat in Central Asia was started as early as the eighties of the last century. In Georgia it was started just ten years later. At that time it was recommended to render the mud-flows harmless by doing afforestation work in the erosion basins.

It was only after the Great October Socialist Revolution of 1917 that soil erosion and mud-flow combat was taken over by the state and transferred to a planned basis. Immediately after the revolution, drastic steps were taken to protect the forests against fire and irresponsible felling. In most of the mountain areas lumbering and cattle grazing was forbidden. Somewhat later, mountain melioration work was resumed with the main emphasis on mud-flow combat.

At present extensive work is being conducted in the country to develop the mountain regions and that is why mountain melioration is called upon to improve the water regimen, to combat soil erosion and the formation of mud-flows and also to raise the productivity of the mountain areas. These tasks call for broader measures. Great attention is now devoted to the use of valuable tree species, nut and fruit trees in afforestation work. Orchards and vineyards are now being laid out in the mountains of Central Asia and the Crimea.

Extensive use is being made of hydro-engineering installations to combat mud-flows in Central Asia, the Trans-Caucasus and other mountain regions of the Soviet Union. Their main purpose is to ensure safe discharge of the mud-flows beyond the area directly threatened by them.

The experience accumulated during the eight decades of work shows that the best results in combatting soil erosion and the formation of mud-flows in the mountain regions are achieved through the large-scale sowing

of perrenial crops, laying out of orchards, vineyards and so on. Hydro-engineering installations alone are powerless to combat soil erosion and the formation of mud-flows they are effective only in combination with other measures.

Mountain melioration research in the Soviet Union is conducted on a very large scale. It is aimed at studying the nature of the erosion and mud-flow processes and developing effective measures to combat these hazards. Mountain melioration work entails big labour expenditure and this is one of the reasons why persistent attempts have been made to reduce the cost of this work and to make it less labour absorbing.

Extensive research has been conducted in the filed of mechanization of agriculture on mountain slopes and means of combatting soil erosion and mud-flow formation. Trials of various highway construction machinery and other implements carried out by the Central Asian Forestry Research Institute and the U.S.S.R. Forestry and Mechanization Research Institute and their adaptation to work in mountains, have made it possible to develop machinery which is capable to operate on slopes with a gradient of 35 and even 40°.

Various research centres and designing bureaus study the problem of soil erosion and mud-flow combat with the ultimate aim of working out efective methods. This work is being co-ordinated by the Standing commission on Soil Erosion at the Dokuchayev Soil Institute and also the Mud-Flow Commission under the Institute of Geography of the U.S.S.R. Academy of Sciences. A number of Union republics in the U.S.S.R. have also set up erosion and mud-flow commissions.

Mountain melioration work carried out in the country pursues the task of improving the water regimes, preventing, stopping or at least reducing soil erosion and mud-flow processes, raising the productivity of the mountain territories and bringing back into agriculture the land that had been lost as a result of erosion. Protective measures must envisage steps which would ensure the restoration of productivity of the mountain areas and the adjoining plains. There must be full consideration for the requirements of the national economy and the physical and geographical features of the region in which mountain melioration work is conducted.

In some regions, mountain melioration work may pursue other tasks as well, such as the utilization of mud-flow discharge for water supply and irrigation, propagation of perrenial grasses.

Practical experience and research data show that the solution of the above-mentioned tasks may be acieved only through combining organizational, forestry, melioration, farming and other measures.

ORGANIZATIONAL MEASURES

1. Correct utilization of mountain areas with rational specialization of enterprises envisaging both profitable operation and prevention of soil erosion and mud-flow formation.

2. Improvement of the composition and state of the mountain forests, raising up their melioration and economic significance.

3. Pasture improvement, raising of the productivity and soil protecting qualities.

FARMING MEASURES.

1. Introduction of farming methods which ensure effective protection against erosion.
2. Application of farming methods in growing crops on mountain slopes which prevent surface runoff and soil erosion.
3. Growing of perrenial crops, technical crops, orchards, vineyards, etc.

AFFORESTATION MEASURES

1. Afforestation of the mountain slopes.
2. Forestry work in the river valleys.
3. Forestry work in the mud-flow cones.

MELIORATION MEASURES

1. Melioration measures along the mountain slopes.
2. Construction of hydro-engineering installations along the mud-flow beds.
3. Construction of hydro-engineering installations at the mud-flow cones and at the sites which require protection.

The measures aimed at improving the water regimen, soil-erosion and mud-flow combat and the raising of the productivity of the mountain areas must embrace the entire watersheds of the mudflows. If these measures are inadequate and do not remove the threat of mud-flow formation, they should be carried out within the cones of the mud-flows as well.

All this explains why the organizational and the other measures are so important in the mountain areas. They are aimed at facilitating the restoration of a powerful vegetation which would raise the erosion resistance and productivity of the mountain soil.

The combination of anti-erosion and anti-mud-flow measures must vary for the different types of soil and land. On land under the State Forest Reserve, all the work is concentrated at the maximum building-up the woods, at the overgrowing of all the glades and other forestless spaces. There must also be extensive afforestation work on the State Land Reserve. As for the land used by the collective farms—there, the erosion and mud-flow combat must be carried out in accordance with the requirements of stemming up to the maximum and to retain the land under cultivated crops.

SUMMARY

The natural factors and manifestations of soil erosion and mud-flows in the mountain areas of the Soviet Union are analized. The researches carried out in connection with these processes, the management, agrotechnical-, melioration -and afforestation measures, which have to be applied with a view of soil conservation, are shown.

RÉSUMÉ

On analyse les facteurs naturels et les formes sous lesquelles se manifestent l'érosion et les coulées boueuses dans les régions montagneuses de l'U.R.S.S.

On expose les recherches effectuées concernant ces processus, les mesures d'organisation, agrotechniques, amélioratives et d'afforestation à appliquer en vue de la conservation du sol.

ZUSAMMENFASSUNG

Es werden die natürlichen Faktoren sowie die Äusserungsformen der Bodenerosion und Schlammströme in den Gebirgsgegenden der Sowjet-Union analysiert.

Es werden die Untersuchungen dargelegt, die im Zusammenhang mit diesen Prozessen durchgeführt wurden, sowie die organisatorischen, agrotechnischen, meliorativen und Bewaldungsmassnahmen, die für die Bodenkonservierung angewandt werden müssen.

SOME OBSERVATIONS ON THE SOIL EROSION IN THE MOUNTAIN REGIONS OF THE ARMENIAN S.S.R.

KH. P. MIRIMANIAN [1]

The Armenian S.S.R. is a mountainous country, having profound canyons, fertile valleys, mountain plateaus and high snowy peaks. The mountain- relief of Armenia is the result of mountain forming processes and of volcanic activities. The immense thickness of the eruptive rocks of Armenia is composed of basalts, trachytes, tuffs, etc., while the folded mountains are of ancient sedimentary rocks. The elevation of Armenia is from 600 to 4 000 m. above sea level. It is surrounded onall si des by high ranges, therefore it has a variable continental climate. The summer is very hot, up to 40°C, and the winter is snowy and very cold, up to 33°C. The mean annual temp. is from 4—12°C, and the average annual precipitation is from 250—600 mm. The vegetational cover is very different — in the lower part of the republic at the height of 700—1,000 m. semi-desert vegetations is observed, while in the uplands of 1,500—2,000 m. — mountain steppes (Stipa Stenophylla, etc.) and still higher beautiful alpine meadows may be observed. Under the influence of the mentioned natural conditions, we find semi-desert, very slighty humous carbonate soils, culture- irrigated humous soils, salines and alkali soils, chestnut moderately humous soils, very humous deep black soils (chernozems), mountain-meadow strongly humous quite leached soils, bog soils, forest soils have been formed in Armenia. In Armenia, different natural and, first of all, mountainous conditions have contributed to the wide spread of soil erosion.

In the case of the acceleration of erosion on the mountain slopes, land color gradually changes from dark to light humous deficient subsoil and the yield of the field declines progressively. The soil erosion in the mountain regions of Armenia greatly depends on different conditions of land cultivation, declination and spread of the mountain slopes, types of soils and parent rocks, rainfall, exposure of slopes, vegetative cover and so on.

Our many years' investigations bring us to the following conclusions about some regularities in regard to the development of soil erosion in Armenia, namely:

In the upper parts of the mountain slopes, the degree of soil erosion is less. In the middle parts of the slopes it becomes sharper, and in the lower

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parts the degree of soil erosion somewhat declines, depositing a certain amount of solid matter. And all this is reverberated upon the thickness of humous horizon of soils, humus content and texture of soils on the above mentioned parts of the slopes. For example on the slopes of Ilandag (Akhta region) we have the following data:

Elevation	Thickness of humous horizon (cm)	Humus (%)	The sum of fractions % < 0,01 mm
2200 m	62	7.7	50—70
1800 m	40	3.00	26—30
1600 m	100	4.5	32—45

In those cases, when the mountain slopes are covered with forest and thick peat grass vegetation to the water-demarcation line, the soil erosion takes place very slowly, frequently runoff is absent or it is not dirty (Agmagan). But where the forest vegetation covers only the middle parts of the slopes and higher than the forest, the meadow-grass is destroyed by cattle or the land is ploughed, the forest does not save the soil from erosion: runoff passes through the forest, containing a great amount of solid matter (Kirovakan, Dilijan).

Further, in the development of soil erosion the exposure of slopes play a great role, the soils on the northern slopes having more organic matter, more thickness and heavy texture and are covered with thick soddy grass, therefore soil erosion on those slopes takes place very slowly. But on the southern slopes, in similar conditions the thickness of humus horizon of soils is small, organic matter is less, texture is light — the soil erosion is very strong. For instance, near the village of Solak, we have the following figures:

	Thickness	Humus %	CO_2 %	The sum of fraction % < 0,01 mm	The sum of fraction % 3—0,25 mm
Northern slopes	60 cm	5.5	4.3	64.6	18.8
Southern slopes	30 cm	0.8	13.5	37.3	47.0

In Armenia one of the most important factor of soil erosion is the melting of snow and the runoff of the snow water. When the snow melts very quickly and the soil is frozen to the depth of 10—20 cm, we observe a very great loss of solid matter. But in the case, when the soil is not frozen and snow melts slowly, the soil absorbs all snow-melting water, the soil erosion takes place very slowly. From here it is clear that the regulation of snow gathering and melting is very important for controlling soil erosion.

The velocity of soil erosion depends on the nature of soils and parent rocks. The rich thickness, heavy texture and granular black soils of Armenia

are generally less exposed to erosion, and soils which are formed on the volcanic rocks (basaltes), are also less exposed. The soils which contain a little amount of organic matter, are shallow and having light texture, contribute more to erosion. The soils of Armenia, which are formed on fold deposits, lose very easily the upper arable horizon.

Concerning steep slopes, there is a visible difference between flat and rough surfaces: in the case of flat surface, the destruction of the soil is less than that of a rough surface. In the latter case, when the runoff water gathers in the concave areas, the strength of the water increases, and, therefore, the degree of soil erosion is getting bigger.

Ploughing of the lands on steep slopes, overloading of the mountain pastures, excessive exploration of the forests and irregular tilling of soils downwards) — all this favours soil erosion, and on the slopes of 15—20° and more, they form deep furrows (ravines, gullies).

Finally, it is necessary to note that there are other factors of soil erosion too. For instance, by an uniform rainfall, soil erosion is less than in the case when the same amount of rain falls only a short time. On the steeper slopes soil errosion is more visibile than on the less steep ones. Further it was remarked that on larger- size slopes the loss of solid matter is generally higher, than when the distance between the water demarcation line and the bottom of the valley, is smaller.

In view of the short time available for this communication, we limit ourselves to the above mentioned conclusions of our investigations. The government of the Armenian S.S.R. in their special decision of 1958 declared the law of nature protection; in the same decision the government ordered some important measures for protecting soils from erosion, namely: forbidding of ploughing on mountain slopes higher than 16°, and ploughing slopes downwards it was demanded to plant forest trees on the mountain slopes and so on. According to the above mentioned decision of the government, the Commission for the conservation of nature of the Academy of Sciences of the Armenian S.S.R., and other scientific institutions of the Republic suggested a series of measures to control soil erosion, including crop rotation, contour tillage, strip cropping, ploughing of the slopes in the direction of horizontal lines, planting of forests, sowing grasses, terracing and banking of slopes, crossing of ploughlands, deep furrowing through-shape earthing, snow-gathering and so on.

SUMMARY

In the mountain conditions of Armenia, the degree of soil erosion and destruction of soils depends on the natural vegetation, declination of mountain slopes,types of soils and parent rocks, exposition of slopes, land cultivation and so on.

For the conservation of soils in Armenia, crop rotation, planting of forests, sowing grasses, terracing and banking of slopes, horizontal ploughing, trough-shape earthing, deep furrowing, contour tillage, strip cropping, snow-gathering and so on, are proposed.

RÉSUMÉ

Dans les conditions des montagnes de l'Arménie le degré d'érosion et de destruction du sol dépend de la végétation naturelle, de la déclivité des pentes montagneuses, des types de sols et de roches- mères, de l'exposition des pentes, de la culture du sol, etc.

Pour la conservation des sols en Arménie, on propose l'assolement, l'afforestation, l'ensemencement des herbes, l'aménagement de terrasses et l'endiguement des pentes, le labour horizontal, la pratique de sillons profonds, le labour suivant les courbes de niveau, les cultures en bandes, l'entassement des neiges.

ZUSAMMENFASSUNG

In den Gebirgsverhältnissen Armeniens hängt der Grad der Bodenerosion -und Bodenzerstörung von der natürlichen Vegetation, von der Neigung der Gebirgsabhänge, von den Bodentypen und dem Muttergestein, von der Auslage der Abhänge, von der Bodenbearbeitung usw. ab.

Für die Bodenerhaltung werden Fruchtfolge, Aufforstungen, Begrasungen, Einrichtungen von Terrassen und Eindämmungen der Abhänge, horizontales Pflügen, Tieffurchenziehung, Konturarbeiten, Streifenkultur, Schneezusammenscharungen usw. empfohlen.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

VI. 12

ELECTRIC CONDUCTIVITY OF THE SATURATION EXTRACT AS AN INDEX OF SOIL SALINITY

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INTRODUCTION

Salinity could be considered as one of the major problems that affect productivity in Egyptian soils; as perennial irrigation joined with inadequate drainage, maintain the water table at a level near the soil surface. This leads to high evaporation and salt accumulation which causes soil salinity.

Saline soils are those containing amounts of soluble salts enough to hinder normal economic plant growth. Such soils are found either in small spots among non saline cultivated lands or forming large cultivated areas. They also comprise the whole part of barren lands in the Nile Valley and Delta, and are included in the horizontal expansion program. The effect of soluble salts in the soil on growing plants depends upon several factors the most important of which are:

1) kind and amount of salts,
2) distribution of salts in the soil profile,
3) soil texture and water permeability,
4) kind of plant and its salt-tolerance,

This proves the necessity of soil analyses and estimating the degree of soil salinity for successful cultivation and soil reclamation.

THE OBJECT OF THE PRESENT INVESTIGATION

The present study aims at:

1) the comparison between evaluating the degree of soil salinity by measuring the electric conductivity of saturated soil paste extract, and by determining the soils soluble salt content;

2) studying the relationship between the electric conductivity and the concentration of soluble salts in the saturation extract.

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Several methods were adopted for determining soil salinity that include the extraction of water -soluble salts from the soil and the subsequent determination of salts in the solution obtained.

The method for the extraction of soluble salts varies according to the aim and methods of analyses. Breazeales and McGeorge (1926), stated that usually the digestion of soil in 20 fold its weight of distilled water at 100°C, yields practically all of the sodium carbonate present. Piper (1950), suggests a 1 : 5 soil water extract for the determination of soluble salts.

Many workers prefer to run the estimation at lower limits of humidity. Burd and Martin (1923), expose 2 kilograms of soil after the addition of 400 ml of distilled water, to a high pressure reaching 100 lbs per square inch for obtaining the soil extract. Reitmeier (1946) uses the pressure membrane for obtaining the solution in a similar manner. Displacement methods were applied by White and Ross (1937), for the extraction of soil solution within the field moisture range. The U.S. Salinity Laboratory applies the saturated soil paste extract for the determination of soluble salts (Richards, 1954).

Changes in the soil to water ratio applied for the extraction of soluble salts affect the determination, owing to the varying solubilities of the different salts and ion exchange between the clay complex and the solution. Accordingly, it is more reliable to appraise salinity and determine the different soluble salts using extracts of the soil solution in the field moisture range. These extracts would indicate the salt concentrations to which the plant roots are subjected in the field.

However, difficulty in obtaining such extracts which are time consuming and require special instalations, makes that the saturated soil paste extract seems to be the most convenient extract used in routine analyses for the following reasons;

1. Ease of preparing the paste and obtaining the extract by vacuum filtration.

2. The saturation percentage is directly related to the field capacity. The amount of salts in solution is usually estimated by either of the following methods:

a) gravimetry, which is the most accurate method;

b) the electrical resistance or conductivity of the extract from which rapid tentative salt concentration may be contributed. This is a more recent technique which has long been used for estimating soluble salts in soils (Whitney and Means 1897);

c) the total weight of the different soluble cations and anions after estimating them separately. This yields approximate results. It is usually used only to cross -check results of complete soil extract analyses by comparing the actually weighed total soluble salts with the calculated sum of weights of the different ions in solution.

Research was carried out to study the relationship between electric conductivity and concentration of soluble salts. Kaddah (1953) studied this relation in (1 : 20) soil water extracts of 67 soil samples. Eid and El-eithy (1958) deter-

mined the electrical conductivity and the amount of soluble salts in (1 : 5) soil water extracts of 50 soil samples and found a higly significant correlation of 0.937.

Several arbitrary limits for salinity have been suggested for distinguishing saline from non-saline soils. Kearney and Scofield (1936), Sigmond (1938), considered that plants begin to be adversely affected as the salt content of the soil exceeds 0.1%, while Thompson (1957) considers that saline soils contain more than 0.2% soluble salts. Scofield (1942), considers a soil to be saline when the solution extracted from its saturated paste has an electrical conductivity value of 4 mmhos/cm or more at 25°C. This is adopted by the U.S. Salinity Laboratory and also by the soil Survey Section of the Egyptian Ministry of Agriculture, as follows:

Conductivity of saturation extract in mmhos/cm at 25°C	Degree of soil salinity
Less than 4 mmhos/cm	Nonsaline
From 4—8 mmhos/cm	Moderate salinity
From 8—16 mmhos/cm	High salinity
More than 16 mmhos/cm	Very high salinity

MATERIALS AND METHODS

Selection of samples

58 soil samples differing widely in their texture, soluble salts, calcium carbonate, and gypsum contents were selected for the conduction of the present investigation.

Methods of analyses

1. The saturation extract. The saturated soil pastes were prepared and the extracts obtained according to the method recommendend by Richards (1954).

2. The 1 : 20 soil water extracts. 25 grams of each soil sample were shaken with 500 mls. of distilled water in a wrist action mechanical shaker for a period of an hour. The mixture was then filtered to obtain the soil extract.

3. Determination of electric conductivity, total of soluble salts, and different cations and anions in the previous soil water extracts (Richards 1954).

4. Sulphates were determined by difference between the sum of cations and that of the other estimated anions.

5. Total soluble salts (Piper, 1950) : A suitable volume of the soil extract (50 mls in case of 1 : 20 soil water extract, and 5 mls in case of the saturation extract) was evaporated to dryness and the oven dry residue (at 105°C) weight was obtained.

RESULTS AND DISCUSSION

From table 1 it can be shown that:

a) Soil samples no. from 1 to 13 with electric conductivites of saturated paste extract, less than 4 mmhos/cm at 25°C, have a low content of soluble salts not exceeding 0.14% as determined in the paste extract. According to the limit widely applied to saline soils as those having more than 0.2% soluble salt content, these soil samples are beyond the limit and thus considered as nonsaline. This agrees with their consideration as non-saline regarding the electrical conductivity of the saturation extract and the salinity classification scale adopted by the soil survey section.

Table 1

Electrical conductivity determined in saturated and diluted extracts (1 :20)

Sample No.	Saturation percentage	Saturation extract determinations		1 : 20 soil water extract determinations	
		Electrical Conductivity mmhos/cm at 25°C	T.S.S. % (on soil basis)	Electrical Conductivity mmhos/cm at 25°C	% T.S.S. (on soil basis)
1	19	0.73	0.010	0.08	0.18
2	77	0.87	0.054	0.15	0.24
3	24	1.68	0.032	0.10	0.21
4	75	1.85	0.096	0.19	0.38
5	37	1.96	0.046	0.09	0.16
6	80	2.00	0.102	0.14	0.29
7	66	2.23	0.092	0.70	1.36
8	36	2.29	0.072	0.21	0.41
9	38	2.60	0.059	0.15	0.22
10	52	3.00	0.097	0.22	0.37
11	72	3.25	0.141	0.25	0.48
12	33	3.75	0.107	0.20	0.35
13	42	3.90	0.103	0.25	0.52
14	65	4.20	0.222	0.29	0.50
15	66	4.36	0.198	0.29	0.54
16	73	4.70	0.303	0.42	0.67
17	72	5.18	0.331	1.12	1.82
18	60	5.21	0.230	0.28	0.36
19	53	5.50	0.214	0.27	0.37
20	18	6.10	0.070	0.11	0.16
21	100	6.72	0.600	0.59	0.91
22	37	6.82	0.175	0.58	1.03
23	88	7.20	0.595	2.56	4.94
24	73	7.60	0.448	0.47	0 72
25	91	7.72	0.550	0.65	0.99
26	28	7.95	0.170	0.20	0.38
27	79	8.05	0.510	0.50	0.64
28	23	8.40	0.120	0.21	0.35
29	41	8.60	0.310	1.10	1.66

Table I (continued)

Sample No.	Saturation percentage	Saturation extract determinations: Electrical Conductivity mmhos/cm at 25°C	Saturation extract determinations: T.S.S. % (on soil basis)	1 : 20 soil water extract determinations: Electrical Conductivity mmhos/cm at 25°C	1 : 20 soil water extract determinations: % T.S.S. (on soil basis)
30	26	8.70	0.190	0.23	0.42
31	85	9.20	0.700	1.53	2.34
32	67	9.90	0.570	1.12	1.70
33	77	10.40	0.710	0.72	1.10
34	79	11.00	0.670	0.68	0.96
35	46	11.70	0.360	0.54	0.95
36	89	13.30	1.140	2.09	3.71
37	66	14.20	0.910	1.14	1.76
38	66	14.60	0.780	1.00	1.46
39	45	14.80	0.460	0.68	0.90
40	66	15.70	0.690	0.80	1.09
41	66	17,00	0.810	0.86	1.19
42	92	17.50	1.180	0.90	1.18
43	22	20.30	0.340	0.44	0.67
44	21	24.46	0.340	0.42	0.79
45	98	26.90	1.940	1.59	2.30
46	63	34.20	1.690	2.34	3.20
47	22	38.90	0.590	2.28	3.84
48	42	42.40	1.440	2.39	3.80
49	24	44.50	0.790	2.93	5.18
50	30	55.60	1.170	3.37	5.47
51	47	65.30	2.950	2.90	4.24
52	18	66.70	0.850	2.70	4.33
53	92	75.40	6.190	5.50	6.89
54	39	86.20	3.190	3.50	4.97
55	38	89.18	3.300	4.52	7.02
56	80	91.90	6.370	5.72	7.48
57	30	112.20	2.920	5.10	8.08
58	24	127.30	2.570	4.06	6.11

When soil salinity is determined from the soluble salts estimated in 1 : 20 soil water extract for these samples, higher values are obtained. The estimated soluble salt percentages in this case range between 0.16% and 0.52% with the exception of sample no. 7 which shows a higher salt percentage (1.36%) due to the presence of higher amounts of calcium sulphate (gypsum).

b) In samples from no. 14 to 26 with electrical conductivities ranging between 4 and 8 mmhos/cm in the saturation extract, the soluble salts percentage (expressed on soil basis) fluctuates between 0.17 and 0.6% as determined in the same extract except for sample no. 20 where it is found to be 0.07%. Sample no. 20 represents a sandy soil with a low water saturation percentage of 18%. Most of these samples have a salt content, as determined in the saturation extract, surpassing the limit 0.2% for nonsaline

soils except for the sandy soil sample No. 20, 26 and also in the medium textured soil sample No. 22 where it happens to be 0.07, 0.17 and 0.18% respectively. These last 3 samples are considered moderately saline in view of electric conductivity rates, and nonsaline with respect to their estimated salt contents.

The soluble salt content of this group of samples as determined in 1:20 soil water extract amounts from 0.36 to 1.03%. Thus they are considered as saline, except for the sandy soil sample No. 20 where it is found to be 0.16%. In samples No. 17 and No. 23, rich in gypsum, this percentage rises up to 1.82 and 4.94% respectively.

c) The third group of soil samples (from No. 24 to No. 40) with saturation extracts having electrical conductivities in the range from 8 to 16 mmhos/cm, revealed soluble salt contents ranging from 0.31 to 1.14% except for samples No. 28 and 30 that have sandy texture where it decreased to 0.12 and 0.19% on soil basis respectively as determined in the saturation extract.

Using 1:20 soil water extract for the determination of salinity in this batch of samples, resulted in the soluble salt percentage varying between 0.64 and 1.76%, with the exception of the two sandy soil samples No. 28—30 where it came down to 0.35 and 0.42% respectively. In the two soil samples No. 31 and 36 that contain high amounts of gypsum, this percentage amounted to 2.34 and 3.71% respectively. Thus soil samples from No. 27 to No. 40 could be considered as highly saline in regards to either electric conductivity or soluble salt percentage expressed on soil basis.

d) Soil samples (from No. 41 to No. 58) in which the electrical conductivity of the saturation extract exceeded 16 mmhos/cm at 25°C, the determined soluble salt content of these soils exceeded 0.8% when determined in the saturation extract. In the sandy soil samples No. 43, 44, 47 and 49 the percentage diminished to 0.34, 0.34, 0.59 and 0.79% respectively. Soil sample No. 56 had the highest value of 6.37%.

In the soil water extract (1 : 20) the estimated soluble salts ranged between 1.18 and 8.08% expressed on soil basis, whereas in soils of coarse texture (samples No. 43 and 44) it happened to be 0.67 and 0.79% respectively.

In fact, a great difference does exist between evaluating soil salinity from electric conductivity measurements and from soluble salt percentage determinations. Electric conductivity indicates salt concentration in solution and this varies in soils of different texture that have the same salt content but differ in their saturation percentages.

Table 2 including the analyses of some typical samples, holds evidence to the effect of varying texture on the disagreement of salinity estimation from electric conductivity of saturation extracts with appraising salinity from soluble salt percentages.

Referring to tables 1 and 2, an appreciable increase is verified in the amount of salts, present in soil, that is soluble in 1 : 20 soil water extract than that in the saturated paste extract. This influences considerably

Table 2

Soil salinity appreciated by measurements of electrical conductivity and percentage of soluble salts

Sample	Saturation Percentage	Saturation extract Determinations				1:20 Soil water Extract Determinations	
		E.C. mmhos/cm.	Salinity Degree	T.S.S. % (on soil Basis)	Salinity Degree	T.S.S. % (on Soil Basis)	Salinity Degree
4	75	1.85	nonsaline	0.096	nonsaline	0.384	moderate
5	37	1.96	"	0.046	"	0.160	nonsaline
14	65	4.20	moderate	0.222	moderate	0.500	moderate
15	66	4.36	"	0.198	nonsaline	0.540	high
11	72	3.25	nonsaline	0.141	"	0.480	moderate
20	18	6.10	moderate	0.070	"	0.160	nonsaline
28	23	8.40	high	0.120	"	0.350	moderate
29	41	8.60	high	0.310	moderate	1.660	very high
31	85	9.20	high	0.702	high	2.340	very high

the soluble salts percentage (on soil basis) as determined in both extracts. Such an increase may be referred mainly to:

1. Gypsum content of the soil, as its low solubility limits the amount soluble in the saturated soil paste extract, while using a higher water to soil ratio, as in the case of 1:20 soil water extract permits the solubility of larger amounts of the gypsum present in soil. Usually, the soluble gypsum in the saturation extract does not appreciably exceed an amount equivalent to 0.2% on soil basis, even though, the soil gypsum content may be considered as high as 10 fold this amount, while it would be completely soluble in a 1: 20 soil water extract and thus raises the estimated soluble salts percentage in soil as will be shown in the following table.

From table 3 it can be shown that the increase in the percentage of total soluble salts when determined by using the 1 : 20 soil water extract, is accompanied by a corresponding increase in both the sulphate and calcium ion concentrations. This may add further evidence to the solubility of more calcium sulphate (gypsum) as being the cause of most of the percieved increase in soluble salts.

Table 3

Relationship between the increase of the soluble salt per cent and the increase of the concentration of sulphate and calcium ions

Sample No.	Saturation extract determinations				1:20 Soil water extract determinations		
	E.C. mmhos. at. 25°C	T.S.S. % on soil basis	me/100 gm soil		T.S.S. % on soil basis	me/100 gm soil	
			Ca	SO_4		Ca	SO_4
17	5.18	0.33	2.09	2.23	1.82	15.44	22.22
23	7.20	0.60	2.11	7.02	4.94	49.10	64.83
36	13.30	1.14	1.97	14.49	3.71	20.60	46.58
49	44.50	0.79	2.06	2.86	5.18	59.16	63.56
50	55.60	1.17	5.13	3.90	5.47	61.20	63.04

2. An increase in the estimated soluble cations, especially sodium, despite the high solubility of its salts. The increase is mainly referred to hydrolysis of the soil adsorption complex and the release of some of the adsorbed cations in solution.

The amount of released ions depends upon the constitution and concentration of the external solution. Usually sodium forms the majority of the released ions owing to the instability of sodium clay. Results confirming such hydrolysis are presented in the following table 4.

Table 4

Increase in sodium and total increase in cations

Sample No.	Milliequivalente per 100 grams of soil									
	Saturation Extract Determinations				1 : 20 Soil water extract Determinations				Increase in Sodium	Total increase in Cations
	Ca + Mg	Na	K	Total	Ca+Mg	Na	K	Total		
10	0.090	1.456	0.026	1.572	0.50	4.06	0.146	4.706	2.60	3.13
13	0.140	1.483	0.052	1.675	0.60	5.10	0.170	5.870	3.62	4.20
22	Traces	2.550	0.017	2.567	0.46	10.50	0.400	11.360	7.95	8.79
26	0.154	2.269	0.011	2.434	0.33	4.00	0.120	4.450	1.73	2.02
30	1.050	1.690	0.022	2.762	1.20	2.98	0.122	4.302	1.29	1.54
39	0.310	7.200	0.360	7.870	0.18	12.80	0.500	13.480	5.60	5.61

The increase in sodium in the samples shown in table 4 cannot be referred to either solubility of higher amounts of sodium salts, nor to more exchange with other soluble cations. The increase in the sum of carbonates and bicarbonates (table 5) that might be formed by reaction of the released sodium ions with CO_2 dissolved in solution, could give further evidence for such a trend.

From table 5 it could be noted that in samples No. 13, 22 and 30 the increase in sodium equals approximately the increase in the sum of carbonates and bicarbonates. On the other hand in samples No. 10, 26 and 39 the

Table 5

Increase in sum of Carbonates and bicarbonates

Sample No.	Milliequivalentes per 100 grams of soil						
	Saturation extract		1 : 20 Soil Water Extract		Increase in sum of CO_3 + HCO_3 (A)	Increase in Na (B)	$\frac{A}{B}$ %
	CO_3	HCO_3	CO_3	HCO_3			
10	—	0.114	—	2.00	1.89	2.60	72.70
13	0.042	0.193	0.20	3.70	3.66	3.62	101.10
22	—	0.780	1.04	7.76	8.02	7.95	100.80
26	—	0.045	—	1.40	1.36	1.73	78.70
30	—	0.042	—	1.34	1.30	1.29	100.80
39	—	0.090	0.20	2.12	2.23	5.60	39.80

increase in sodium exceeds the increase in the sum of carbonates and bicarbonates indicating exchange between adsorbed sodium and divalent cations.

Correlation of E.C. values to salt concentrations:
Statistical analyses revealed a highly significant correlation under 1% probable error, between electrical conductivity and concentration of soluble salts as shown in the following table. (6)

However, it should be clearly pointed out that calculating salt concentrations from electrical conductivity values, gives only tentative results owing to variations in the ionic composition of the measured solutions. This is due to the great differences existing between the equivalent conductivities of the different ions and to variations in their degree of hydration.

Table 6

Correlation of E. C. values to salt concentrations

Kind of relationship	Correlation coeficient	Remarks
a) E.C. and T.S.S. in me/L	0.994	For E.C. values less than 4 mmhos/cm
	0.935	E.C. values between 4 and 8 mmhos/cm
	0.924	for E.C. values between 8 and 16 mmhos/cm
	0.992	for E.C. values more than 16 mmhos/cm
b) E.C. and T.S.S. in g/L	0.953	for E.C. values less than 4 mhos/cm
	0.881	for E.C. values from 4 to 8 mmhos/cm
	0.818	for E.C. values from 8 to 16 mmhos/cm
	0.988	for E.C. values more than 16 mmhos/cm

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SUMMARY

Fifty eight soil samples that differ in their texture and salt content were selected for this investigation to examine the two methods widely used in the estimation of soil salinity namely;

a) determination of electrical conductivity in the saturated soil paste extract;

b) determination of the total soluble salts percentage on soil basis using the saturation and 1 : 20 soil water extracts.

The results obtained could be summarized in the following points:

1. The electrical conductivity of the saturated paste extract is the most suitable method that may be applied in soil classification for indicating the different degrees of soil salinity.

2. The corelation between electrical conductivity and concentration of soluble salts is highly significant, though it is too difficult to transform conductivity units into precisely corresponding salt concentration as the relationship is complex and is greatly affected by the kind of salts present, the degree of their ionization and the extent of hydration of their ions.

RÉSUMÉ

Dans cette recherche 58 échantillons de sols différents comme texture et teneur en sel ont été sélectionnés afin d'examiner les deux méthodes largement employées dans l'évaluation de la salinitée du sol.

a) détermination de la conductibilitée électrique dans l'extrait saturé de la pâte de sol;

b) détermination du pourcentage total de sels solubles à base de sol, en utilisant des extraits de saturation et des extraits d'eau de sol 1 : 20.

Les résultats obtenus ont conduit aux conclusions suivantes:

1. La conductibilitée électrique de l'extrait de pâte saturée est la méthode la plus convenable qui puisse être appliquée dans la classification du sol pour indiquer les différents degrés de la salinitée du sol.

2. La corrélation entre la conductibilité électrique et la concentration de sels solubles est très significative, quoiqu'il soit trop difficile de convertir les unités de conductibilitée en concentrations salines correspondant exactement étant donné que les relations sont complexes et hautement influencées par la qualité des sels présents, par leur degré d'ionisation et l'étendue de l'hydratation de leurs ions.

ZUSAMMENFASSUNG

58 Bodenproben, deren Textur und Salzgehalt verschieden sind, wurden für diese Untersuchung gewählt, um die zwei weitverbreiteten Methoden in der Abschätzung der Bodensalzhaltigkeit zu prüfen, und zwar:

a) Bestimmung der elektrischen Leitfähigkeit im Bodenpaste-Extrakt;

b) Bestimmung des Prozentsatzes des gesamten löslichen Salzes an der Bodenbasis unter Verwendung von Sättigungsextrakten und Bodenwasserextrakten im Verhältnis 1 : 20.

Die erzielten Ergebnisse könnten in den folgenden Punkten zusammengefasst werden:

1. Die elektrische Leitfähigkeit des gesättigten Pasteextraktes ist die geeigneteste Methode,

die in der Bodenklassifikation angewendet werden könnte, um die verschiedenen Stufen des Bodensalzgehaltes anzugeben.

2. Die Korrelation zwischen elektrischer Leitfähigkeit und Konzentration löslicher Salze ist höchst bezeichnend obwohl es zu schwer ist, Leitfähigkeitseinheiten in genau entsprechende Salzkonzentration umzusetzen, da die Beziehung komplex und durch die Natur der vorhandenen Salze, den Grad ihrer Ionisation und den Umfang der Hydratation ihrer Ione höchst beeinflusst wird.

DISCUSSION

S. S. SINGH (Sweden). The author has determined the electrical conductivity of saturation extract of some soils and then the total soluble salts in 1 : 20 extract of those soils. Without giving any reason, he has concluded that saturation extract method is better because of the three points given in his text. As far as I know, these three points are well known in principle and they do not come from his studies. May I know what is new contribution about Egypt soils from his paper?

A. M. GAITH. The contribution is in the Egyptian soils; it is found for rating the salinity for the purpose of the land classification adopted now in Egypt, that E.C. is most suitable for that, according to the reasons I mentioned in the paper under 8/a and b.

I. SZABOLCS (Hungarian People's Republic). Do you determine the chemical composition of the salt content of soils mentioned in your paper, parallelly with the analysis of saturation extract?

A. M. GAITH. Beside the conductivity, all soluble anions and cations in the saturated soil extract are determined.

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VI. 13

BIOLOGICALLY INDUCED SOIL ALKALINITY

P. JANITZKY [1]

INTRODUCTION

The role of sodium carbonate in the development of solonetzic soils has been widely recognized and various explanations for its formation and occurrence in soils have been summarized and discussed (Kelley, 1951; Antipov-Karataev, 1953).

Field and laboratory studies have supported the conclusion that relatively large amounts of HCO_3 and CO_3 may accumulate in salt-affected soils in different parts of the world, which are influenced by particular microbiological reduction processes (Abd-El Malek and Rizk, 1963; Antipov-Karataev, 1953; Gracie et al., 1934; Whittig and Janitzky, 1963; Lynn, 1963; Janitzky and Whittig, 1964).

The occurrence of strongly alkaline soils appears to be closely associated with presently or previously water-logged depressional areas supporting a profuse marsh vegetation. In the anaerobic environment soluble sulphates in the groundwater are converted to sulphides by bacterial activity. The sulphide hydrolyzes and precipitates as iron sulphide. The hydroxyl ion produced by hydrolysis reacts with CO_2 released from decomposing organic matter to form bicarbonate. HCO_3 can thus be formed as a secondary product, in contrast to other anions such as Cl and SO_4, and may not necessarily be found in waters entering the depressional areas.

The anaerobic environment, has a sufficiently high content of organic matter to serve as an energy source for the microorganisms, and availability of sulphates supplies the essential ingredients for continual generation of bicarbonate. As a rule, these areas occupy the lowest positions in the terrain and the HCO_3 produced is carried upward to surrounding higher elevations during evaporation of the groundwaters. In certain cases, however, HCO_3 may drain to still lower depressional areas. Some lakes in Egypt are surrounded by zones of swamp vegetation. Waters collecting in the lakes become strongly alkaline after passing through the swamp belt which acts as a transformer of SO_4 to HCO_3 (Abd-El-Malek, 1963). Similar situations may be observed

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in some areas in California, but in general soils most severely affected by soluble carbonates in the Sacramento Valley are located along the rims of flood plains and basins which are presently, or have in the past been, inundated.

The lower Sacramento River Basin is dissected by sluggish, intermittent creeks and sloughs discharging dissolved material either to the Sacramento River or into flat, poorly-drained basins isolated from the river by its natural levees. Localized anaerobic environments develop along the course of the sloughs and give rise to excessive alkalinity in narrow zones in soils bordering the sloughs (Whittig and Janitzky, 1963). These zones widen gradually until they fuse with other creeks at lower elevations to form extensive bodies occupying the rims of the marshes in the basins.

The mechanism of formation and accumulation of $NaHCO_3$ and Na_2CO_3 have been described in detail by same authors (1963) for soils along the drainageways, where proeminent changes in reaction, concentration of $HCO_3 + CO_3$, and percentage of exchangeable Na were observed within short distances of not more than 3 to 5 meters.

Incubation experiments under controlled laboratory conditions have revealed that conversion of alkali sulphates into alkali carbonates may occur in one and the same soil medium if anaerobic conditions and sufficient organic matter are provided for microbial activity (Antipov-Karataev, 1953; Lynn, 1963; Janitzky and Whittig, 1964).

Results of the present investigation reveal that the processes of development of alkalinity demonstrated in localized areas may also be manifest over rather extensive areas.

THE SOILS INVESTIGATED

Studies were conducted to clarify the successive phases in the accumulation of Na_2CO_3 in soils on the rims of basins along the Sacramento River. The area investigated forms the southern edge of the Yolo Basin and flanks the lower course of Lindsey Slough, a tributary of the Sacramento River. Prior to reclamation some forty years ago, the greater part of the area was periodically flooded and supported a dense growth of tule vegetation (*Typha angustifolia*). A drainage canal now separates this region from the saline areas surrounding it, as indicated by the dashed line in the schematic drawing of the location of the sampling sites (fig. 1).

The sequence of soils studied extends gradually from sea level to approximately 1. 5 m elevation over a distance of 1. 5 km and ranges from a nonsaline organic Wiesenboden (Profile No. 1) over weakly saline and alkaline Wiesenboden (Profile No. 2) to Solonetz and Solonchak of increasing alkalinity and salinity (Profiles No. 3,4 and 5). Although the first three sites are presently under cultivation and may have undergone some changes in the surface horizons as a result of cultivation, the continuity in the soil formation process and the genetic relationship between the previously inundated organic soils and the solonetzic soils beyond the canal still remain well recogni-

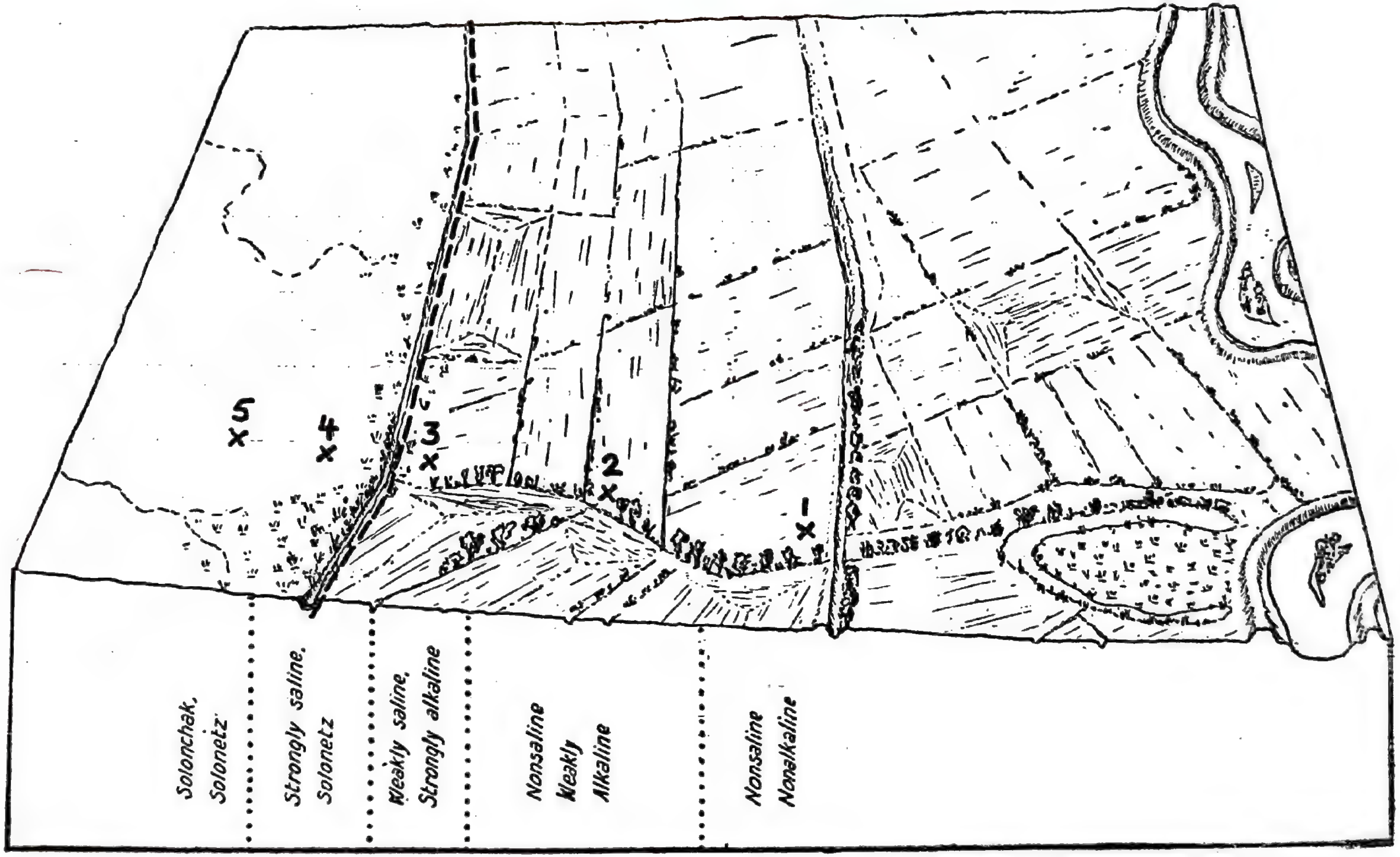

Fig. 1. Schematic drawing of the location of the sampling sites.

Table

Chemical properties

Profile No.	Depth (cm)	pH	E.C.* (mmhos/cm)	Ca (me/100g) solu-ble	Ca (me/100g) exch-ang.	Ca (me/100g) as $CaCO_3$	Mg (me/100g) soluble	Mg (me/100g) exchang.	Mg (me/100g) as $MgCO_3$
1	0— 13	6.1	1.0	0.2	19.9	7.3	0.3	21.9	3.2
	13— 26	6.1	0.5	0.1	21.4	5.9	0.2	21.2	4.0
	26— 38	6.0	0.7	0.2	22.3	4.9	0.2	20.4	4.8
	38— 64	5.8	1.6	0.4	17.5	8.5	0.6	20.9	3.1
	64— 81	5.7	2.9	0.7	18.2	7.9	1.4	23.0	4.0
	81—112	6.2	3.5	1.0	19.1	5.6	1.8	27.1	4.1
	112+	6.8	3.5	1.1	18.9	6.1	1.8	28.4	3.0
Groundwater (me/l)				21,9			32.1		
2	0— 13	7.8	0.8	0.1	11.4	76.3	0.3	18.2	77.9
	13— 38	7.9	0.6	0.1	8.9	36.3	0.2	18.8	86.1
	38— 69	8.0	1.2	—	3.6	28.0	0.2	19.9	130.1
	69—102	8.4	1.2	—	1.4	11.3	0.1	18.1	242.5
	102—127	8.4	1.2	—	1.3	10.2	0.1	20.2	47.1
	127+	8.6	1.2	—	1.6	20.0	0.1	19.6	35.1
3	0— 15	7.6	1.2	0.2	15.0	38.0	0.3	15.9	37.7
	15— 33	8.6	1.7	—	7.2	60.7	0.1	14.1	58.6
	33— 51	9.3	2.4	—	2.2	30.3	—	4.7	56.5
	51— 74	9.5	2.5	—	1.0	22.3	—	2.7	50.2
	74—102	9.6	3.3	—	0.7	20.9	—	2.4	41.9
	102—127	9.6	4.8	—	0.7	28.5	0.1	3.1	38.9
	127+	9.5	4.2	—	0.1	68.5	0.1	3.4	41.4
4	0— 5	8.1	3.9	0.1	5.2	12.4	0.1	6.2	16.4
	5— 20	9.2	2.9	—	2.1	14.0	0.1	2.4	23.0
	20— 43	9.6	2.9	—	0.8	8.4	—	1.4	33.1
	43— 61	9.6	4.3	—	0.5	8.6	—	1.8	46.4
	61— 79	9.8	4.9	—	0.3	10.0	—	3.2	87.8
	79— 91	10.0	5.0	—	0.2	5.6	0.1	5.9	60.1
	91—107	9.8	4.1	—	0.4	41.4	0.2	5.2	51.9
	107—122	9.5	2.9	—	0.5	20.1	0.1	6.0	20.7
	140+	9.3	2.8	—	1.0	73.6	0.6	9.6	40.5
5	0—1.5	6.1	46.8	0.7	0.7	3.5	1.9	0.8	3.1
	1.5— 5	8.4	8.7	0.1	2.6	3.3	0.1	2.6	8.2
	5— 18	9.1	11.8	0.1	1.6	10.2	0.1	1.4	15.9
	18— 41	9.5	6.9	—	0.7	5.9	—	0.9	20.9
	41— 56	9.5	5.4	—	0.3	4.6	0.1	1.6	23.3
	56— 76	9.5	4.7	—	0.3	5.7	0.1	2.5	29.1
	76— 92	9.5	4.5	—	0.2	6.6	0.1	3.8	26.2
	92—114	9.4	3.9	—	0.8	31.3	0.1	3.7	36.0
	125+	9.3	3.6	—	1.4	90.7	0.1	4.5	44.8

* Electrical conductivity.

1

of the soils studied

Na (me/100g)		Cation Exchange Capacity (me/100g)	Exchangeable Na %	Anions (me/100 g)			
soluble	exchang.			CO_3	HCO_3	SO_4	Cl
0.2	1.1	58.0	2	—	0.1	0.4	0.2
0.1	1.0	54.0	2	—	0.1	0.2	0.1
0.1	1.0	54.0	2	—	0.1	0.3	0.1
0.4	1.6	54.0	3	—	0.1	1.0	0.2
0.7	1.7	60.0	3	—	—	2.6	0.3
0.9	1.9	58.0	3	—	—	3.3	0.4
0.8	2.0	56.0	4	—	—	3.4	0.4
14,0				—	4.6	57.8	6.7
0.2	0.9	62.0	1	—	0.2	0.1	0.1
0.2	1.0	34.4	3	—	0.2	0.1	0.1
0.6	3.3	30.0	11	0.1	0.2	0.4	0.1
0.7	4.3	26.4	16	0.1	0.2	0.4	0.1
1.0	6.2	29.0	21	0.1	0.3	0.4	0.2
1.2	7.2	29.0	25	0.1	0.4	0.5	0.2
0.7	2.4	40.0	6	0.1	0.6	0.2	0.1
2.3	14.1	38.4	37	0.2	0.7	1.1	0.4
4.8	29.6	40.8	73	1.1	0.9	2.7	0.5
6.1	34.7	40.8	85	1.5	0.7	3.7	0.6
7.5	34.9	38.4	91	1.9	0.8	5.0	0.7
9.2	33.2	37.2	89	2.1	0.8	5.3	1.0
8.0	29.2	33.2	88	1.1	0.6	5.4	1.2
2.9	10.3	26.4	39	0.1	0.6	0.9	1.4
4.9	28.3	35.6	79	0.5	0.7	2.2	1.9
5.5	32.9	37.2	88	1.4	0.8	2.4	1.2
8.0	30.4	34.4	88	1.6	0.7	5.1	1.5
10.6	26.6	34.4	77	3.3	1.0	5.3	1.6
12.4	23.2	35.6	65	4.4	1.4	5.4	1.8
10.3	22.1	35.6	62	2.9	1.0	4.4	1.6
7.0	21.0	34.4	61	0.9	0.5	3.7	1.8
5.5	17.3	31.2	55	0.5	0.5	2.6	1.8
20.5	3.5	9.8	36	—	0.1	21.7	2.4
9.2	18.8	29.0	65	0.1	0.4	5.7	2.9
16.0	30.0	37.2	81	0.2	0.4	13.1	2.5
11.2	29.6	40.0	74	1.1	0.6	7.7	3.3
10.6	26.6	34.4	77	1.2	0.6	6.5	3.5
10.1	24.3	32.4	75	1.0	0.5	5.8	3.4
9.6	22.8	30.0	76	1.2	0.6	4.8	3.5
8.7	19.3	29.0	66	1.1	0.6	4.4	3.4
6.6	18.8	25.4	74	0.6	0.6	3.0	2.8

zable. Since the groundwater level has been lowered artificially in the area, iron sulphide can no longer be detected in the soils. Prominent iron mottles together with layers of blue-gray color in the subsoil of the organic soil,however, indicates that the soil-although slowly oxidizing-has been in a strongly reduced condition.

RESULTS AND INTERPRETATION

Procedures employed in the determination of pH, electrical conductivity, soluble salts, exchangeable cations, cation exchange capacity, and precipitated Ca + Mg have been previously described in detail (4,7). The results obtained from analysis of the soils are presented in table 1.

Profile 1. This soil, located in the bottom of the depression at about 30 cm below sea level, reflects the influence of groundwater standing at 90 cm depth and containing relatively high concentrations of Ca and Mg (32.1 and 21.9 me/l, respectively) toghether with some Na (14.0 me/l). SO_4 is by far the dominant anion (57.8 me/l), whereas HCO_3 and Cl are present only in small amounts (4.6 and 6.7 me/l, respectively).

The pH is lowest near the middle of the profile. This is perhaps due to reoxidation of preexisting FeS and formation of acid salts in the layers of strongest mottling. The concentration of SO_4 increases sharply from the horizon with the lowest pH value (5.7) downward. HCO_3 disappears correspondingly, being neutralized by H ions produced by FeS oxidation, and the amount of Ca + Mg precipitated as carbonate is small. The high cation exchange capacities throughout the profile reflect the high contents of organic matter. Exchangeable Ca and Mg dominate uniformly on the exchange sites throughout the profile, whereas exchangeable Na remains very low, reaching only in the bottom layer a maximum of 4 per cent. The salinity level as expressed by the electrical conductivity is low in the upper horizons, but increases steadily to a maximum of 3.5 mmhos/cm in the bottom horizons.

Although underlain by moderately saline groundwater, this profile may be genetically considered as the earliest nonsaline and nonalkaline phase in the salt accumulation process within the area, since the soil is saturated with Ca and Mg, and at least the upper part of the profile is essentially free of soluble salts.

Profile 2. Progressing from the lowest position, significant differences are apparent in the profiles situated at higher positions. Profile 2, which lies a few centimeters above sea level, has groundwater at 150 cm and is considerably lighter in color than profile 1, suggesting a smaller content of organic matter.

As groundwater moves away from the zones of SO_4 reduction and HCO_3 generation and becomes more saline by evaporation along the slope, Ca and Mg precipitate as carbonates for two reasons. First, because of increasing aeration and higher temperature in the relatively drier soil, and the decreasing organic matter as source of CO_2, the concentration of CO_2 in solution

is less. The lower CO_2 concentration decreases the solubility of Ca $(HCO_3)_2$ and $Mg(HCO_3)_2$, leading to their precipitation. Secondly, the loss of CO_2 results in conversion of $NaHCO_3$ to Na_2CO_3, which in turn accelerates the precipitation of divalent cations due to rising alkalinity. Ca and Mg being progressively inactivated, Na more effectively competes for exchange sites.

Profile 2 is an example of the first alkalinization phase under the influence of increasing concentration of Na_2CO_3. The profile is sharply divided into two parts, reflecting the upward direction of the alkalinization process. The boundary lies at approximately 40 cm depth. The layers above still resemble the first profile with respect to absolute amounts of soluble and exchangeable ions, although the reaction is already on the alkaline side (pH = 7.8), exchangeable Ca is markedly depressed, and both $CaCO_3$ and $MgCO_3$ exceed 10—25 times the amounts at the surface of the first profile. With the appearance of soluble CO_3 below 40 cm (0.1 me/100 g), both soluble and exchangeable Ca are strongly affected, the former disappearing entirely from the soil solution, the latter remaining in very small amounts (1.3 me/100 g). The pH increases to 8.6 with depth, and exchangeable Na reaches 25 per cent in the bottom layer. The conditions for Na absorbtion are so favorable in presence of Na_2CO_3 that Na does not accumulate in solution. While the exchangeable Na increases in the bottom horizon from 2.0 me/100 g in the first profile to 7.2 in the second, the respective increase of soluble Na is only from 0.8 to 1.2 me/100 g.

Noteworthy is the different behavior of Ca and Mg. Whereas the amount of exchangeable Ca drops from approximately 20 me/100 g in the first profile to as low as 1.3 me/100 g in the second profile, the same values for exchangeable Mg are 23 and 18.1, respectively. This means that Mg is displaced by Na to a much smaller extent than Ca. The following profiles will give further evidence of this phenomenon. This is not incompatible with the fact that soluble Mg is precipitated as $MgCO_3$ in amounts more than 20 times larger than is Ca. The groundwater in the first profile contains more Mg than Ca to start with.

Profile 3. Located close to the edge of the reclaimed area, this soil has had minimum cultivation because of its extremely unfavorable properties. Beneath the surface 15 cm. layer, with weakly expressed salinity and alkalinity, lies a subsoil in which the effect of Na_2CO_3 comes to full expression. The horizon with maximum exchangeable Na (91 per cent) moves gradually upward and coincides aproximately with the horizon of highest concentration of soluble CO_3 in the profile (1.9—2.1 me/100 g). Exchangeable Ca drops in the lower subsoil to negligible amounts (0.1 me/100 g). Exchangeable Mg also becomes strongly suppressed, although not nearly as much as Ca (approximately 3.0 me/100 g), and some traces of Mg are still in solution in the bottom layers (0.1 me/100 g).

Carbonates of the divalent bases continue to accumulate throughout the profile. Evaporation of the groundwater leads to a concentration of the soil solution. With exception of soluble Ca and Mg, all other soluble ions begin to accumulate in increasing amounts with their maximum, as expressed by the conductivity (4.8 mmhos/cm), lying somewhat below 100 cm depth.

Profile 4 is a virgin soil located beyond the canal which borders the reclaimedbasin. It supports a dense cover of saltgrass (*Distichlis spicata*). This profile can be defined as the phase in which the development of alkalinity reaches its peak. The entire soil is strongly alkaline already, with the surface horizon having 39 per cent exchangeable Na. The layers with maximum Na saturation have moved upward to 20 cm depth from 75 cm in the preceding profile. Exchangeable Mg correspondingly is at a minimum in this layer (1.4—1.8 me/100 g). Again, of particular interest is the different behavior of exchangeable Mg as compared to exchangeable Ca. While exchangeable Ca remains low throughout the profile, exchangeable Mg is low only where Na reaches 30.4 and 32.9 me/100 g (88 per cent). In the soil below, exchangeable Mg increases immediately regardless of increased soluble Na, and traces of Mg in solution are still found at pH 10.0 and in presence of 4.4 me/100 g of soluble CO_3. This horizon with extreme alkalinity seems to form a much stronger barrier for Ca than for Mg in the movement of these ions in upward direction. Ca does not even appear in the soil solution at 140 cm depth, and it is rapidly displaced and strongly precipitated far below the layer of 79—91 cm. Within this horizon and above, the content of exchangeable Ca reaches a minimum of 0.2 or 0.3 me/100 g, and $CaCO_3$ drops abruptly from 41.4 to 5.6 me/100 g and remains relatively low in the upper part of the profile, which means that the source of Ca begins to become exhausted at this point in the soil sequence. Mg, on the contrary, is not considerably intercepted by the highly alkaline horizon and continues to migrate through the profile, as the uniformly high values of $MgCO_3$ indicate, beginning to decrease slightly only in the upper 40 cm the soil.

As compared to the shift of the horizons of maximum alkalinity in the profile, the translocation of the layers with highest salinity is not quite so pronounced. The zone of maximum concentration of soluble salts, especially Na (12.4 me/100 g), $CO_3 + HCO_3$ (5.8 me/100 g), and SO_4 (5.4 me/100 g), has moved up only to 80 cm (as compared to 102 cm in Profile 3). The concentration of these soluble salts, however, is much higher in Profile 4 than in Profile 3 (Na 9.2 me/100 g, $CO_3 + HCO_3$ 2.9 me/100 g, and SO_4 5.3 me/100 g). For the first time in the sequence, Cl also begins gradually to appear in the soil solution. Its relative maximum (1.9 me/100 g) has moved closer to the surface than that of the other anions because of its greater solubility and mobility.

Profile 5. In this soil salt accumulation reaches its maximum expression. Soils beyond this distance from the center of the basin show evidence of leaching. The profile occupies a very slightly elevated position in the generally smooth landscape, but it is strikingly distinguished by an almost barren surface. The salts of this soil are concentrated at the very surface in a thin powdery layer which has a conductivity of 46.8 mmhos/cm. Na_2SO_4 forms the bulk of the salts, without any admixture of Na_2CO_3, as indicated by the absence of soluble CO_3 and a pH of 6.1 This might also be a very early sign of beginning leaching, since both the exchange capacity and exchangeable bases are unusually low (9.8 and 5.0 me/100 g, respectively).

Beneath this thin surface layer the soil returns abruptly to conditions similar to those of the preceding profile. The general trend in distribution of soluble and exchangeable ions has still remained the same. Exchangeable Na has increased to 65 per cent within the upper 5 cm, and carbonates of Ca and even of Mg are markedly depressed in the upper part of the profile. Nevertheless, it appears that the alkalinization process is already about to decline, neutral salts still continuing to accumulate. The concentration of $CO_3 + HCO_3$ has decreased considerably (1.8 me/100 g maximum), the pH does not exceed 9.5, and Ca and Mg slowly come back into solution, beginning from the surface (0.7 and 1.9 me/100 g respectively). Soluble Ca is present to a depth of 18 cm and soluble Mg is present in all horizons in small amounts (0.1 me/100 g) Exchangeable Mg is lowest in the 18—41 cm horizon (0.9 me/100 g), which is lower than in any other horizon of all profiles studied, disregarding the still lower value (0.8 me/100 g) in the possibly leached surface. Cl has doubled in concentration (as compared to profile 4) and contributes, together with SO_4, to the gradual shift from alkaline to neutral salts.

CONCLUSIONS

Groundwater containing soluble alkali sulfates and passing through soils of high organic matter content induces specific microbial reduction processes by which it becomes increasingly alkaline during evaporation in surrounding soils. In the course of accumulation of Na_2CO_3 among other soluble salts in these soils, divalent exchangeable bases are progressively inactivated as insoluble carbonates, giving way to the development of alkalinity in the soils. Comparing the average values of the chemical characteristics for the profiles, it appears that the development of solonetzic properties antecedes step by step both vertically within one profile and horizontally in the succesive soils the maximum salt levels in the respective soils. Thus the alkalinity peak as expressed by pH and concentration of exchangeable Na and soluble $CO_3 + HCO_3$ must lie somewhere between the third and fourth profile.

The last profile shows a retrogression of these factors, whereas the concentration of the neutral Na salts comes to a maximum only in this last profile, after a continuous increase through the preceding soils.

Within one and the same soil the strongest Na-absorption has the similar tendency to occupy horizons which are somewhat closer to the surface or relatively further away from the layers influenced to a greater extent by the groundwater and containing the comparatively highest amounts of neutral salts. As discussed previously, this distribution may be observed in profiles 3 and 4. Related to this is also the distribution of exchangeable Mg, the amounts of which are relatively lowest in the horizons above those of maximum salt content in the profiles mentioned.

It is believed by the author that the soils investigated are closely related genetically, since they represent just phases of one continuous soil forma-

tion process. An understanding of the genetic relationship of soils of this and similar sequences can materially aid in classification and mapping.

It is further believed by the author that the processes described have influenced the distribution of presently strongly leached soils with solonetzic structure throughout the Central Valley of California at times when this valley was a large, shallow lake bearing marsh vegetation and developing along its banks sequences of alkaline soils similarly to the profiles investigated.

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SUMMARY

Investigation of a former periodically submerged flood plain in the Sacramento Valley in California revealed a close relationship between anaerobic biological processes in depressional areas and composition of accumulating salts in soils bordering the plain. Bacterial reduction of SO_4, in conjunction with oxidation of organic matter, leads to accumulation of HCO_3 ion in ground waters. In the process of migration and evaporation of the solutions the concentration of Na and soluble $CO_3 + HCO_3$ increases, resulting in precipitation of divalent cations as carbonates and a preferential adsorption of Na in the soils. The presence of soluble $CO_3 + HCO_3$ in the soil solution renders the system strongly alkaline.

RÉSUMÉ

Des recherches sur une plaine alluviale autrefois périodiquement inondée de la vallée de Sacramento en Californie a révélé une relation serrée entre les processus biologiques anaérobiques dans des aires de dépression et la composition des sels qui s'accumulent dans les sols bordant la plaine. La réduction bactérienne du SO_4, conjointe à l'oxydation de la matière organique, mène à l'accumulation des ions HCO_3 dans les eaux phréatiques. Dans le processus de migration et d'évaporation des solutions, la concentration de Na et de $CO_3 + HCO_3$ solubles augmente, résultant dans la précipitation de cations bivalents en carbonates et d'une adsorption préférentielle de Na dans les sols. La présence du $CO_3 + HCO_3$ soluble dans la solution de sol rend le système fortement alcalin.

ZUSAMMENFASSUNG

Untersuchung über ein früher periodisch überschwemmtes Hochwasserbett (Aue) im Sacramento-Tal in Kalifornien hat eine enge Beziehung zwischen anaeroben biologischen Prozessen in den Bodensenken und der Zusammensetzung der sich ansammelnden Salzen in den die Ebene angrenzenden Böden offenbar gemacht. Die bakteriologische Reduktion von SO_4 in Verbindung mit Oxydation des organischen Stoffes führt zur Akkumulation von HCO_3-Ionen in den Grundwassern.

Im Verlaufe des Prozesses der Wanderung und Verdunstung der Lösungen erhöht sich die Na- und lösliche CO_3+HCO_3-Konzentration, welche sich als Fällung zweiwertiger Katione als Karbonate und als bevorzugte Adsorption von Na in den Böden äussert. Die Gegenwart von löslichem CO_3+HCO_3 in der Bodenlösung bewirkt, dass das System stark alkalisch wird.

DISCUSSION

É. TIMAR (Hungarian People's Republic). Regarding the main points of the very interesting paper of Mr. Janitzky, they are in accordance with the experiments made on alkali and saline areas on the Hungarian lowland. I agree with the author regarding the importance of biological processes in the formation of Na_2CO_3 in some soils. The quality and quantity of organical compounds in soils are fundamental in order to examine the biological soda forming processes. First of all, the elementary H is developing as a result of the biological decomposition of the organical compounds of the soil. This can be taken as a fundamental material for the metabolism of Desulfonibric desulfuricans micro-organisms.

Parallely with the anaerobic conditions, as studied in model experiments in soil columns, in laboratory, the redox potential of the environments sharply decreased until -200 mv. Such conditions are very suitable for the activities of Desulfonibrio desulfuricans micro-organisms. In the above mentioned soil columns, however, the original soil contained nearly 20 per cent organic matter. The process of biological soda formation through the reduction of sulphates started only after adding cellulose or Ca-lactate to the soil.

A. H. I. MOUSTAFA (Egypt). I would like to add to Dr. Janitzky's paper that late Dr. Gracie and myself showed in our communication No. 148 of 1934 that the alkalinity of similar soils of Egypt is due to the reducing effect of Desulphuricans Microsphera. We showed also in this paper that the effect of this reducing process is that the Ca and Mg are precipitated as calcium carbonate and magnesium silicate, thus leaving the exchangeable sodium to the dominant ion and causing the alkalinity of the soil.

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VI. 14

INITIAL DECALCIFICATION DUE TO OXIDATION OF SULPHIDES IN YOUNG MARINE SOILS IN THE NETHERLANDS

P. J. ENTE [1]

INTRODUCTION

In the Netherlands recent marine and brackish sediments generally contain certain amounts of sulphides and calciumcarbonate. In reclaiming these sediments the sulphides become oxidised. The sulphuric acid which is then formed reacts with calciumcarbonate, giving amongst other compounds gypsum. The gypsum will be leached rather quickly under the given climatical conditions. This process means an extra loss of calciumcarbonate as compared with the normal decalcification due to the formation and leaching of bicarbonate. The extra loss of calciumcarbonate during the first few years after the emergence of a polder from the water can be called initial decalcification (in accordance with the expression: initial soil formation, for the physical and chemical processes occuring during the first decades after reclamation of an alluvial soil (Zonneveld, 1960; Smits et al., 1962).

Although a decalcification due to the oxidation products of the sulphides is generally accepted, up to now it has not been proved quantitatively in the field. However the soil analysis data obtained in the reclamation of the former Zuiderzee bottom have made a survey worth while.

AVAILABLE DATA

In the area of the North-Eastern-Polder at three different periods samples have been collected, which have been analysed for calciumcarbonate (gasvolumetric method of Scheibler). The first sampling was carried out in the virgin sea bottom [2], before emergence of the polder in 1942. The other sets of samples have been taken during, respectively after, the reclamation.

In the area of the polder Eastern Flevoland (which fell dry in 1957) also one set of samples was collected from the virgin sea bottom. A second set was collected during the reclamation.

[1] Agric. Res. Dept. Zuiderzee polders Development Authority Kampen, NETHERLANDS.

[2] For our present survey it is not important that after enclosure of the Zuiderzee in 1932 the enclosed part (now called Ijsselmeer = Lake Ijssel) became fresh.

It should be noticed that with regard to the sites of sampling the respective sets had no relation to each other.

It will be explained here why only a part of the samples could be used. Given the relation between the calciumcarbonate content and the clay content (Verhoeven, 1963: the calciumcarbonate content being lowest in the light textured soils and reaching a constant high value in soils with a clay content of more than 17 per cent) the numbers of the light textured and heavy textured soils should be equally spread in the different sets. This not being the case only samples with a clay content of more than 17 per cent were selected. On the other hand in making this restriction those soils were also left out of account in which no initial decalcification could be expected because of the low content of sulphides (De Köning and Wiggers, 1955: content of sulphides increasing with increasing clay content).

The sampling depth of the different sets being not exactly the same the present survey had to be restricted to the areas being sufficiently homogeneous in a vertical sense with regard to the calciumcarbonate content. In these areas only the topsoil could cope with this problem. It may be remarked that the horizontal homogeneity for calciumcarbonate was sufficiently high.

Another kind of data was available from plots at which sampling had been carried out at regular intervals to study the initial soil formation.

About 25 plots were selected. In some of the samples also sulphurous compounds had been determined.

RESULTS

The result of the "random" samples is given in table 1.

From table 1 two conclusions can be drawn.

Firstly the initial decalcification amounted to 0.6—0.7 per cent $CaCO_3$. Secondly the initial decalcification was restricted mainly to the first 3 to 5 years after emergence of these polders.

The results of the periodically sampled plots are shown in table 2.

These figures only confirm the already given conclusions and stress the importance of the first years after emergence.

DISCUSSION

In table 2 a figure for the virgin sea bottom is lacking. However on 14 of the 25 plots, sampling had been carried out immediately after the plots had fallen dry. The average obtained at this time did not differ from the average obtained from the samples collected one year after emergence, which means the first year played no role in the initial decalcification.

During the first 5—10 years after the emergence of a polder large areas are drained imperfectly, for rain water has to go a long way over the surface to the scarce main drains. Very soon a dense vegetation develops (in Eastern

Table 1

Initial decalcification in some Zuiderzeepolders

Area	Stage	Number of samples	$CaCO_3$-content * and mean error **	Initial decalcification and mean error
North-Eastern polder I	virgin sea bottom before emergence of polder	13	11.0 ± 0.4	0.6 ± 0.4
	5—6 years after emergence	9	10.4 ± 0.2	0.8 ± 0.4
	17-21 years after emergence	15	10.2 ± 0.1	0.2 ± 0.2
polder Eastern Flevoland II	virgin sea bottom before emergence of polder	22	11.4 ± 0.2	0.6 ± 0.2
	3½ years after emergence (average)	27	10.8 ± 0.1	
polder Eastern Flevoland III	virgin sea bottom before emergence of polder	17	11.6 ± 0.2	0.7 ± 0.3
	3 years after emergence (average)	16	10.9 ± 0.3	

* In g per 100 g of dry soil (Scheibler).
** Van Uven (1946).

Table 2

Initial decalcification and aeration in eastern Flevoland

Number of years after emergence of polder	$CaCO_3$-content and mean error	Depth in cm/of an aeration of $> 80\%$ *
1	11.0 ± 0.1	3.6
2	10.7 ± 0.1	8.8
3	10.2 ± 0.1	23.5
4	10.2 ± 0.1	29.3
5	10.1 ± 0.1	35.4
6	10.1 ± 0.2	

* Aeration judged on colour visually.

Flevoland already in the second year). Depending on the conditions of rainfall, evapotranspiration and natural drainage (runoff), one area can be more or less marshy alternatively. So the rapid progress in aeration and decalcification after the second year (table 2) can be explained by an exceptionally dry summer. Under normal climatological conditions the decalcification would have been a little slower probably.

The objection could be made that the demonstrated decalcification results from a high CO_2-production of the vegetation or the micro-organism under these marshy conditions. However, four plots producing a dense

vegetation on the one half and being kept fallow for the other half, showed au almost equal decalcification in both type of treatment in a periodical sampling, thus excluding the influence of the vegetation. Regarding the role of the micro-organisms in the fallow plots it can be stated only that the organic matter content remained constant (3.0 per cent) in the period under discussion, whilst at the same time it is known that the initial organic matter is not easily decomposable (Harmsen, 1958). These conditions do not seem to favour the CO_2-production of micro-organisms.

On the other hand the loss of sulphides in the top soil can be demonstrated clearly, in table 3 (see also Zuur, 1962).

Table 3

Loss of sulphides in Eastern Flevoland

Stage	Content of sulphides *
1. virgin sea bottom	1.47
2. years after emergence	0.93
3. years after emergence	0.85
4. years after emergence	0.82
5. years after emergence	0.72
6. years after emergence	0.75

* Expressed in g SO_4 per 100 g of dry soil and measured as the difference between the amounts of watersoluble sulphates and total sulphurous compounds.

The loss of sulphides appears to be of the same order of magnitude as the decalcification, for 1 per cent of calciumcarbonate is able to neutralize the products of the oxidation of the sulphides corresponding with practically 1 per cent of sulphide (when expressed as SO_4) as present originally. Comparing the demonstrated initial decalcification of 0.6—0.8 per cent in 5 years with the normal decalcification of 1 per cent in 75—100 years (accepted for arable land in the Netherlands : Edelman and De Smet, 1951), the former appears to be more than the tenfold of the latter.

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SUMMARY

In lagoonal sediments of marine to brackish origin an initial decalcification of 0.6—0.8 per cent produced by the oxidation products of sulphurous compounds in the first 3—5 years of the reclamation, could be demonstrated in the field.

RÉSUMÉ

Dans les sédiments des lagunes d'origine marine à saumâtre, on a pu démontrer sur terrain une décalcification initiale de 0,6—0,8% produite par l'oxydation des composés sulfureux, pendant les 3—5 premières années de l'amélioration.

ZUSAMMENFASSUNG

In den Haffablagerungen eines See- bis Brackwasser-Ursprungs konnte im Felde in den ersten 3—5 Meliorationsjahren eine anfängliche Entkalkung von 0,6—0,8%, die durch die Oxydierungsprodukten der schwefeligen Verbindungen hervorgerufen war, nachgewiesen werden.

DISCUSSION

P. JANITZKY (U.S.A.). What were the pH values during the reclamation of the polder?
P. I. ENTE. Neutral, because of the high $CaCO_3$ content.

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VI. 15

DER EINFLUSS DES BEWÄSSERUNGSWASSERS AUF DIE BODENEIGENSCHAFTEN

K. DARAB [1]

Die durch Wechselwirkung zwischen Bewässerungswasser und Boden bedingten Prozesse können in zwei Hauptgruppen aufgeteilt werden.

1. Unmittelbarer Einfluss der Bewässerung, der vor allem darin zum Ausdruck kommt, dass einer der wichtigsten Faktoren der Bodenfruchtbarkeit, das Wasser, regelmässig und in ausreichender Menge bereitgestellt wird.

2. Mittelbarer Einfluss der Bewässerung, der im wesentlichen darin besteht, dass sich der modifizierte Wasserumsatz auf die physikalischen, chemischen und biologischen Eigenschaften des Bodens, damit auf die Bodenbildungsprozesse und als deren Ergebnis auf die Bodenfruchtbarkeit auswirkt, letztere steigert oder in ungünstigen Fällen verringert (Zu den negativen Wirkungen gehören z.B. die der sekundären Moorbodenbildungsprozesse, der sekundären Versalzung, der sekundären Alkalisierung der Böden, usw.).

Vom Gesichtspunkt der Bewässerung können wir zwei Faktoren, hervorheben, die den Wasser- und Salzumsatz der bewässerten Böden und die Menge sowie die chemische Zusammensetzung des Bewässerungswassers beeinflussen.

Von den, die Durchführungsweise der Bewässerung beeinflussenden Faktoren sind vor allem die physikalischen und Wasserhaushaltseigenschaften des Bodens als solche Faktoren zu erwähnen, die sowohl das Bewässerungsprojekt als auch die Menge des Bewässerungswassers, Häufigkeit der Wassergaben und die Bewässerungstechnik entscheidend beeinflussen. Von den physikalischen und Wasserhaushaltseigenschaften der Böden bestimmen das tote Wasser, sowie die in Volumenprozent ausgedrückten Werte des Feuchtigkeitsgehaltes und der natürlichen Wasserkapazität die Menge des Bewässerungswassers, bzw. Stärke der Durchfeuchtung, während das Wasserführungsvermögen zur Projektierung der Bewässerungsanlage und zur Durchführung der Bewässerung zuverlässige Anhaltspunkte bietet.

Die Bewässerung erfordert sehr grosse Beachtung in solchen Fällen, in denen die Böden schlechte bodenphysikalische Eigenschaften besitzen.

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So z.B. bei Böden mit toniger mechanischer Zusammensetzung, wo das tote Wasser relativ hoch und die Menge der aufnehmbaren Bodenfeuchtigkeit niedrig ist, bei Alkaliböden, die ausserordentlich dichte, überschlechte Wasserhaushaltseigenschaften verfügende Illuvialhorizonte besitzen. In letzterem Fall können wir diesen Illuvialhorizont als „toten Horizont", in dem die Wasserbewegung praktisch Null ist, auffassen. Der Boden kann somit jeweils nur den Anteil des Bewässerungswassers aufnehmen und speichern, den der obere Illuvialhorizont infolge seiner natürlichen Wasserkapazität fassen kann. Durch grössere Wassergaben kann demnach die Durchfeuchtung nicht vertieft werden, so dass der obere Horizont übermässig bewässert ist, wodurch Wasserpfützen und Wasserschäden auftreten. Von diesen Grundgedanken ausgehend könnten nach den Wasserhaushaltseigenschaften die Böden der Ungarischen Grossen Tiefebene in folgende sieben Gruppen eingeteilt werden:

1. Böden mit starker Wasseraufnahme, schwachem Wasserhaltevermögen (Sandböden).
2. Böden mit starker Wasseraufnahme, mittlerem Wasserhaltevermögen.
3. Böden mit guter mittlerer Wasseraufnahme, schwachem gutem Wasserhaltevermögen.
4. Böden mit mittlerer Wasseraufnahme, gutem Wasserhaltevermögen.
5. Böden mit mittlerer Wasseraufnahme, starkem Wasserhaltevermögen.
6. Böden mit schlechter Wasseraufnahme, starkem Wasserhaltevermögen.
7. Böden mit sehr schlechter Wasseraufnahme, starkem Wasserhaltevermögen.

DIE EIGENSCHAFTEN DER BÖDEN UND DIE QUALITATIVEN ANFORDERUNGEN AN DAS BEWÄSSERUNGSWASSER

Vom Gesichtspunkt der Bestimmung der an das Bewässerungswasser gestellten qualitativen Anforderungen sind die Eigenschaften der Böden und vor allem der Einfluss des Bewässerungswassers auf die Alkalisierung und Entalkalisierung der Böden zu berücksichtigen und diesbezüglich sind zwei Grundprozesse zu beachten:

1. Die Veränderung des Wasserumsatzes und durch diese die Veränderung des Salzumsatzes des Bodens.
2. Die Veränderung der chemischen Zusammensetzung der Bodenlösung und durch diese die Veränderung der Menge der austauschbaren Natriumionen.

1. Der Charakter des Salzumsatzes des Bodens hängt von den Wasserhaushaltseigenschaften des Bodens, vom Stand des Untergrundwassers und vom Salzgehalt des Untergrundwassers, von der Anwesenheit des „toten Horizonts" und von der Tiefe des toten Horizonts, von der Menge der wasserlöslichen Salze des Bodens usw. ab.

Die Wirkungen dieser verschiedenen Faktoren kommen im Charakter und in der Veränderung des Charakters des Salzumsatzes der Böden zum Ausdruck. Darum liefert der Salzumsatz der Böden eine vielseitige Auskunft über die Dynamik der Alkaliböden. Über die angewandten Meliorations- und agrotechnischen Massnahmen wird der Vergleich des Salzvorrates, die Salzbilanz des Bodens, ein klares Bild bieten.

Bei der Aufstellung der Salzbilanz, — nach Kovda — sind folgende Bilanzelemente zu unterscheiden.

a) Gesamtgehalt des Bodens an löslichen Salzen zum Zeitpunkt des Vergleiches.

b) Die Erhöhung des Salzvorrates (der Salzaufnahme aus dem Grundwasser, mit dem Niederschlagswasser und mit dem Bewässerungswasser zugeführte Salzmenge).

c) Die Verminderung des Salzvorrates (mit dem Niederschlag und mit dem Bewässerungswasser aus dem Boden ausgelaugte Salzmenge, die durch pflanzliche Assimilation aus dem Boden eliminierten Salze).

In den vergangenen Jahren haben wir an einigen Alkaliböden in der Grossen Ungarischen Tiefebene, durch dynamische Messungen, den Salzgehalt des Bodens, die Salzbilanz, zusammengestellt (Tabelle 1). Die Böden waren Alkaliböden oder alkalisierte Wiesenböden. In unbewässerten Verhältnissen waren die Salzbilanzen (Szarvas 17, Hortobagy 33) negativ. In dem Fall, wo die Bewässerung mit verhältnismässig geringeren Wassermengen durchgeführt wurde, war die Salzbilanz noch immer negativ, aber die Menge der ausgelaugten Salze war schon niedriger als bei den unbewässerten Böden in diesem Gebiet. Mit der Erhöhung der Menge des Bewässerungswassers ist die Salzbilanz der Böden positiv geworden und der Anteil der mit dem Bewässerungswasser zugeführten Salzmenge wurde mit der Erhöhung der Menge des Bewässerungswassers vergrössert.

Tabelle 1

Die Salzbilanz einiger Alkaliböden der Ungarischen Tiefebene

Profile Nr.	Menge des Bewässerungswassers m^3/ha	Gesamtmenge der Salze des Bewässerungswassers (t/ha)	Lösliche Salze im Boden vor der Bewässerung (t/ha)	Lösliche Salze im Boden nach einem Jahr (t/ha)	Die Veränderung der Gesamtmenge der Salze im Boden (t/ha)
Szarvas 17	—	—	42,58	33,07	— 9,51
Szarvas 6	700	0,21	33,07	26,02	— 7,26
Szarvas 13	2.600	0,78	141,23	144,5	+ 3,27 0,78 Bew. wass. 2,49 Unterg. wass.
Kopáncs 301	15.000	13,0	45,16	60,47	+ 15,31 13,0 Bew. wass. 2,31 Unterg. w.
Hortobágy 33	—	—	57,69	56,78	— 0,91

Diese Ergebnisse zeigen, dass man bei Kenntnis der Salzbilanz nicht nur die verschiedenen Meliorations- und agrotechnischen Verfahren richtig beeinflussen kann, sondern auch die nachhaltige Wirkung der Bewässerung

und die maximal zugelassene Salzkonzentration des Bewässerungswassers berechnen kann.

2. Die Austauschadsorption der Natriumionen kann man für praktische Zwecke mit der Gapon-Gleichung ausdrücken.

$$\frac{Na}{Ca + Mg} = K \frac{(Na^{+})}{\sqrt{\frac{(Ca^{++})+(Mg^{++})}{2}}}.$$

Bei der Anwendung dieser Gleichung soll man Rücksicht auf einige Faktoren nehmen.

a) Der erste Faktor ist, dass das Gleichgewicht des Austausches der Natriumionen von den Anionen der Natriumsalze abhängt. So ist die Menge der eintauschenden Natriumionen von Soda grösser, als von neutralen Natriumsalzen. Darum soll man bei der Beurteilung des Bewässerungswassers die anionische Zusammensetzung beachten und bei der Berechung des maximal zugelassenen Natriumgehaltes die Menge der Natriumionen in Prozent zu den Prozenten „der Summe der Kationen" berücksichtigen.

b) Die Menge der Salze und die chemische Zusammensetzung der Bodenlösung ist anders als die des Bewässerungswassers. Den Unterschied zwichen der Zusammensetzung der Bodenlösung und des Bewässerungswassers zeigt Tabelle 2. An den Ergebnissen kann man sehen, dass die Salzkonzentration und der Natriumgehalt der Bodenlösung eines Alkalibodens zweimal so gross ist als die Salzkonzentration des Bewässerungswassers.

Die Veränderung der Zusammensetzung des Bewässerungswassers hängt vom Salzgehalt des Bodens, von der Hydrolyse der austauschbaren Natriumionen, von der Veränderung der Löslichkeit der Salze ab.

Unter Berücksichtigung des Obengesagten wurde eine Norm für die Zusammensetzung des Bewässerungswassers aufgestellt und die Ansprüche der verschiedenen genetischen Bodentypen der Ungarischen Grossen Tiefebene an das Bewässerungswasser bestimmt. Die häufigsten Bodentypen auf dem bewässerten Gebiet der Tiefebene zeigt Tabelle 3.

Wenn wir innerhalb des genetischen Bodentyps die Faktoren, die bei der Bestimmung der Wasserqualität, bei der Wechselwirkung zwischen Bewässerungswasser und Boden eine Rolle spielen (mechanische Zusammensetzung, Tiefe der wasserversperrenden Schicht, Stand des Grundwassers, usw.), berücksichtigen, können wir einen engen Zusammenhang zwischen den genetischen Bodentypen, ihren Wasserhaushaltseigenschaften und ihrem Wasserbedarf feststellen.

So haben sich im Gebiet jenseits der Theiss die Wiesenböden durch Zusammenwirken des oberflächennahen Grundwassers und einer Gräservegetation ausgebildet und stehen auch heute noch unter unmittelbarem Einfluss des Grundwassers. Das Grundwasser liegt nicht tiefer als 2,0—2,5 m unter der Oberfläche. Die mechanische Zusammensetzung der Böden ist schwer, die Wasseraufnahme mittelmässig; das Wasser wird in der Regel stark gehalten. Diese Böden bedürfen der Bewässerung, die jedoch mit gros-

Tabelle 2

Chemische Zusammensetzung des Flusswassers und der Bodenlösung bei Alkaliböden

Tiefe cm	Feuchtigkeit %	Salzmenge mg/l	HCO_3^-	CO_3^{--}	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	Natriumgehalt %
			mg. äquiv. (mg./l)							
a) Flusswasser		550	225,58 / 3,698	—	35,46 / 1,00	166,46 / 3,46	28,23 / 1,40	17,13 / 0,70	31,17 / 1,35	39
b) Bodenlösung 0—10	37,3	888,31	442,43 / 7,25	18,45 / 0,61	127,64 / 3,60	18,38 / 0,38	35,74 / 1,78	27,26 / 1,14	217,91 / 9,47	76,3
10—20	33,4	748,91	509,47 / 8,35	—	85,10 / 2,40	23,77 / 0,49	14,30 / 0,71	3,47 / 0,14	112,80 / 4,90	85,2
20—40	32,8	795,84	230,58 / 3,78	29,01 / 0,96	163,10 / 4,60	18,38 / 0,38	8,58 / 0,42	13,44 / 0,55	299,95 / 13,04	93,0
40—60	32,3	1554,84	336,67 / 5,84	39,93 / 1,23	387,19 / 10,92	37,26 / 0,77	11,44 / 0,57	17,78 / 0,73	707,57 / 30,76	95,9
60—80	28,7	2393,90	438,41 / 7,81	43,53 / 1,45	230,47 / 6,50	983,16 / 20,46	6,43 / 0,32	9,97 / 0,41	681,93 / 29,65	97,5
80—100	31,7	2342,10	421,02 / 6,90	—	594,26 / 10,76	107,42 / 2,23	19,30 / 0,96	20,82 / 0,86	1179,28 / 51,27	89,7
100—120	30,9	3032,50	430,35 / 7,05	—	471,58 / 13,30	586,36 / 12,20	35,74 / 1,78	124,07 / 5,13	1384,40 / 60,19	96,5
120—140	28,9	4238,26	383,45 / 6,28	—	892,45 / 25,16	1248,45 / 26,61	7,58 / 0,37	176,95 / 7,32	1499,73 / 65,21	89,4

Tabelle 3

Wichtige Bodentypen der bewässerten Flächen in der Grossen Tiefebene und deren prozentuelle Verteilung

Geographische Zone	Bodentyp	In % der bewässerten Gesamtfläche
A. Jenseits der Theiss	Wiesen-Tschernosem	21,7
	Wiesenböden und solonetzartiger Wiesenboden	36,4
	Tiefe Solonetzböden	20,2
	Mittlere und krustige Solonetzböden	19,7
	Alluvialböden	20,0
	Sandböden	8,3
B. Gebiet zwischen Donau und Theiss Sandböden	Humose Sandböden und tschernosemartige Sandböden	45,3
	Wiesenböden	11,0
	Solontschak-Solonetz	31,9
	Alluvialböden	3,5

ser Umsicht durchzuführen ist. Es ist hier zweckmässiger mit kleinen Wassergaben und häufiger zu bewässern.

Bei den austauschbaren Kationen überwiegen Kalzium und vereinzelt Magnesium. Die Menge der austauschbaren Natriumionen ist gering. Der obere Horizont ist oft ungesättigt. Der Gehalt an löslichen Salzen ist gering, doch ist an einigen Stellen, in den tieferen Schichten oder im Unterboden, auch ein grösserer Salzgehalt zu beobachten. Für die Bewässerung ist dieser Bodentyp einer der schwierigsten. Der hohe Grundwasserstand und die schwere mechanische Zusammensetzung lassen nur eine beschränkte Auslaugung der löslichen Salze zu, ausserdem kann infolge des nahen Grundwassers — besonders wenn sich infolge der Bewässerung das Untergrundwasser hebt — auch von unten herauf eine Salzanreicherung erfolgen. Da diese Böden nicht alkalisch und im oberen Horizont ungesättigt sind, kann schon ein relativ niedriger Natriumgehalt des Bewässerungswassers den Eintausch des Natriumions herbeiführen.

Bessere Wasserhaushaltseigenschaften haben die Wiesen-Tschernosemböden in der Tiefebene. Diese kommen meistens in den höheren Lagen der Gebiete, unter denen das Grundwasser tiefer, bei etwa 3—5 m liegt, vor. Ihre mechanische Zusammensetzung ist in der Regel leichter (tonhaltiger Lehm oder Lehm). Das Spektrum des nützlichen Wassers ist breiter. Hier sind auch ohne Bewässerung gute Ernteergebnisse zu erzielen, wenn auch die ertragssteigernde Wirkung der Bewässerung stark zur Geltung gelangt und die Wasserausnützung günstig ist.

Falls in den tieferen Schichten kein schlecht wasserführender Horizont liegt, ermöglichen der tiefe Grundwasserstand und die guten Wasserhaushaltseigenschaften des Bodens die Anwendung auch salzreicheren Bewässerungswassers. Bei der Bestimmung des maximal zulässigen Natriumgehalts für das Bewässerungswasser ist zu berücksichtigen, dass der ursprüngliche, austauschbare Natriumgehalt des Bodens gering ist.

Bei tiefen Solonetzböden sollte man noch mit grösserer Umsicht als bei den Wiesenböden die Bewässerung durchführen und zur Verhütung der

Alkalisierung des A- Horizontes sollte man an das Bewässerungswasser, sowohl in bezug auf Salzgehalt als auch Natriumgehalt, erhöhte qualitative Anforderungen stellen.

Bei mittleren und zur Verkrustung neigenden Solonetzböden kann — falls keine Bodenmelioration vorgesehen ist und nur die Weiden bewässert werden sollen — auch Bewässerungswasser mit relativ höherem Salzgehalt und Natriumgehalt zulässig sein.

ZUSAMMENFASSUNG

Die durch Wechselwirkung zwischen Bewässerungswasser und Boden bedingten Prozesse können in zwei Hauptgruppen eingeteilt werden:

a) Unmittelbarer Einfluss der Bewässerung, der vor allem darin zum Ausdruck kommt, dass einer der wichtigsten Faktoren der Bodenfruchtbarkeit, das Wasser regelmässig und in ausreichenden Mengen bereitgestellt wird.

b) Mittelbarer Einfluss der Bewässerung, der im wesentlichen darin besteht, dass sich der modifizierte Wasserumsatz auf die physikalischen und chemischen Eigenschaften des Bodens und damit auf die Bodenbildungsprozesse und deren Einfluss auf die Bodenfruchtbarkeit auswirkt, letztere steigert oder in ungünstigen Fällen verringert.

Von den die Durchführung der Bewässerung beeinflussenden Faktoren sind vor allem die physikalischen und Wasserhaushalteigenschaften des Bodens zu erwähnen.

Nach der Menge des Bewässerungswassers und Durchführung der Bewässerung teilte man die Böden der Ungarischen Grossen Tiefebene nach ihren Wasserhaushalteigenschaften in sieben Gruppen ein.

Vom Gesichtspunkt der an das Bewässerungswasser gestellten qualitativen Anforderungen, sind die Eigenschaften der Böden und vor allem der Einfluss des Bewässerungswassers auf die Alkalisierung und Entalkalisierung der Böden zu berücksichtigen. In dieser Hinsicht sind zwei Grundprozesse zu unterscheiden:

a) Die Veränderung des Wasserumsatzes im Boden und der dadurch bedingte Salzumsatz des Bodens.

b) Die Veränderung der chemischen Zusammensetzung der Bodenlösung und die dadurch bedingte Veränderung des Gleichgewichtes zwischen den Kationen der Bodenlösung und den austauschbaren Kationen des Kolloidkomplexes des Bodens.

Wenn man innerhalb des genetischen Bodentyps die Faktoren, die bei der Bestimung der Art der Bewässerung und bei der Bestimmung der Wasserqualität eine Rolle spielen berücksichtigt, lässt sich ein enger Zusammenhang zwischen dem genetischen Bodentyp, seinen Wasserhaushalteigenschaften und Anforderungen an die Wasserqualität feststellen.

SUMMARY

Processes determined by the interaction between irrigation water and soil can be divided into two main groups:

a) The direct influence of irrigation is that it provides the plants with water, one of the most important factors in soil fertility, regularly and in satisfactory amounts.

b) The indirect influence of irrigation is that it changes the water regime and the physical, chemical and biological properties of the soil and the soil forming process and as a result it may increase or, under unfavourable conditions, decrease the soil fertility.

From factors influencing the managment of irrigation, first of all the physical and water regime features of the soil should be named. From the viewpoint of the amount of irrigation water and the managment of irrigation, the soils of the Great Hungarian Plain were divided into seven groups according to their water regime characters.

As to the qualitative demands of irrigation water, the characters of the soils and in the first place the influence of the irrigation water on alkalinisation and desalkalinisation of the soils should be taken into account.

In this respect two ground processes must be distinguished:

a) The change of the water regime in the soil and the change of the salt balance the soil caused by the former.

b). The alteration of the chemical composition of the soil solution and the change caused thereby in the equilibrium between the cations of the soil solution and the exchangeable cations in the colloid complex of the soil.

Within the genetic soil type, when taking into account the factors involved in determining the manner of irrigation and the water quality, a close relation can be established between the genetic soil type and its water regime features and water requirement.

RÉSUMÉ

Les changements survenus par l'action réciproque des eaux d'irrigation et le sol peuvent être groupés en deux classes:

a) L'action directe de l'irrigation, qui se manifeste surtout par le fait que l'un des facteurs les plus importants de la fertilité, l'eau, est appliquée régulièrement et en quantités suffisantes.

b) L'action indirecte de l'irrigation, qui consiste essentiellement en ce que le régime d'eau modifié a une certaine influence sur les qualités physiques, chimiques et biologiques du sol, et les processus de la formation de celui-ci, ce qui influence finalement sa fertilité, augmente, ou dans les cas défavorables, la réduit.

Parmi les facteurs qui ont une influence sur le mode d'exécution de l'irrigation il faut mentionner tout d'abord les propriétés physiques et le caractère du régime des eaux du sol. Du point de vue de la quantité d'eau d'irrigation et d'exécution de l'irrigation nous avons classé les sols de la Grande Plaine Hongroise, d'après le caractère de leur régime hydrique, en sept classes.

Au point de vue des propriétés qualitatives de l'eau d'irrigation il faut prendre en considération les propriétés du sol et surtout le rôle de l'eau dans les processus d'alcalisation et de désalcalisation. De ce côté nous pouvons distinguer deux processus fondamentaux:

a) L'altération du régime de l'eau du sol, qui a pour suite l'altération du régime des sels.

b) L'altération de la composition chimique de la solution de sol et l'altération de l'équilibre entre les cations en solution et les cations échangeables du complexe colloïdal du sol.

Si l'on prend en considération, à propos du type génétique les facteurs qui jouent un rôle dans le choix du mode d'exécution de l'irrigation et dans l'appréciation de la qualité de l'eau à employer l'on trouve une corrélation étroite entre le type génétique et les propriétés du sol conditionnant son régime hydrique et son besoin d'eau.

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VI. 16

RÉSULTATS D'UN ESSAI D'IRRIGATION À L'EAU SALÉE EN TUNISIE

J. P. COINTEPAS [1]

PRINCIPE

Les ressources hydroagricoles de la Tunisie se caractérisent par la rareté et une salure généralement élevée des eaux d'irrigation. Les utilisateurs se trouvent donc pris entre deux impératifs contradictoires: limiter les doses d'irrigation à une valeur économiquement rentable et augmenter les doses d'irrigation pour lessiver les sels solubles accumulés dans le sol.

L'expérience décrite ici et réalisée pour le compte du Secrétariat d'État à l'Agriculture de Tunisie, a pour but d'étudier les besoins en eau de quelques cultures et l'évolution de la salure du sol au cours de l'irrigation. Dans la présente note nous n'évoquerons que le problème de la salure du sol.

MILIEU NATUREL

Le climat de Tunis où se situe l'essai est de type méditerranéen semi-aride. La température moyenne annuelle est de 18,3°C. Le pluviométrie moyenne annuelle est de 415 mm, l'évapotranspiration potentielle (ETP) est de 1 410 mm. Les maximums de pluviométrie se situent en Décembre (72 mm) et Janvier (67 mm), le maximum de l'ETP en Juillet avec 220 mm. La parcelle expérimentale est située sur un sol peu évolué, profond sur alluvions limono-argileuses (30 à 40% d'argile, 40% de limon), très calcaires (40% dont 12% de calcaire actif). Les réserves en eau utilisables jusqu'à 2 m sont estimées à 400 mm. La nappe phréatique est profonde: 8 m.

On irrigue soit avec l'eau de la ville (0,2 g/l) soit avec l'eau de la nappe phréatique qui titre 2,68 g/l dont 1,18 g/l de chlore avec un SAR de 5.

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DÉROULEMENT DE L'ESSAI

L'évapotranspiration potentielle étant considérée comme la valeur maximale des besoins en eau d'un couvert végétal continu, les doses d'irrigation sont calculées à partir de l'évapotranspiration potentielle (ETP) mesurée à l'aide d'évapotranspiromètres type Thornthwaite. On restitue au sol soit l'ETP, soit l'ETP diminuée chaque jour d'une valeur constante (1, 2, 4, 6 mm/j). La plante est amenée ainsi à utiliser les réserves d'eau du sol. Cette contribution du sol à l'alimentation en eau des plantes entraîne à la fois le dessèchement de ce sol et l'augmentation de sa salure. D'où une augmentation du potentiel de l'eau qui se traduit pour les plantes par une diminution de leur évapotranspiration réelle et corrélativement de leur rendement. Outre l'effet sur la pression osmotique des solutions du sol, le sel peut également agir par sa toxicité.

La parcelle d'essai comporte trois cultures :

— des oliviers, variété Chétoui, plantés en Octobre 1955 à 6 × 6 m, auxquels on applique trois doses :

- — une dose forte égale à ETP soit 8 000 à 9 000 m³/ha/an,
- — une dose moyenne : ETP- 2,5 mm/jour soit 3 000 à 4 000 m³/ha/an,
- — une dose réduite : ETP — 5 mm/jour (1 500 m³/ha/an),

— des orangers, variété Maltaise demi sanguine et Valencia Late, plantés en 1956 à 4 × 4 m et qui reçoivent les mêmes quantités d'eau que les oliviers ;

— des cultures annuelles recevant les doses, ETP- 1 mm/j, ETP-2 mm/j, ETP — 4 mm/j, ETP — 6 mm/j.

On a pratiqué successivement des cultures de maïs, coton, blé, luzerne (fig. 1).

RÉSULTATS

1. Le sol de la parcelle d'essai avait au départ une conductivité moyenne de 1,0 mm hos/cm. On a vu la salure augmenter progressivement pour atteindre son équilibre à la fin de la deuxième campagne. Le graphique ci-contre correspond aux différentes phases de l'évolution du profil.

2. Une fois l'équilibre atteint, la répartition du sel revêt sensiblement la même forme quelque soit le traitement et correspond à la courbe de la figure 1. La salure globale est d'autant plus forte que la dose est plus importante.

3. La profondeur du maximum de salure varie avec les traitements et la nature des cultures. Pour les oliviers arrosés à la dose ETP ce maximum se situe vers 1,25 ou 1,50 m. À la dose ETP — 2 mm/j il se situe à 0,75 m. À la dose ETP — 5 mm/j il est à 0,50 m. Dans les parcelles d'orangers les profondeurs respectives sont 0,75, 0,50 et 0,50 m. Sous cultures annuelles le problème est plus complexe. En effet pour assurer un bon démarrage des semis on a été obligé d'apporter sur tous les traitements des doses d'eau uniformes égales à l'ETP. Ces doses ont eu pour effet de

faire descendre chaque année le maximum de salure qui est passé progressivement de 0,75 à 1,00 puis 1,25 m.

4. Les conductivités maximales enregistrées varient elles aussi avec les doses et la nature des cultures.

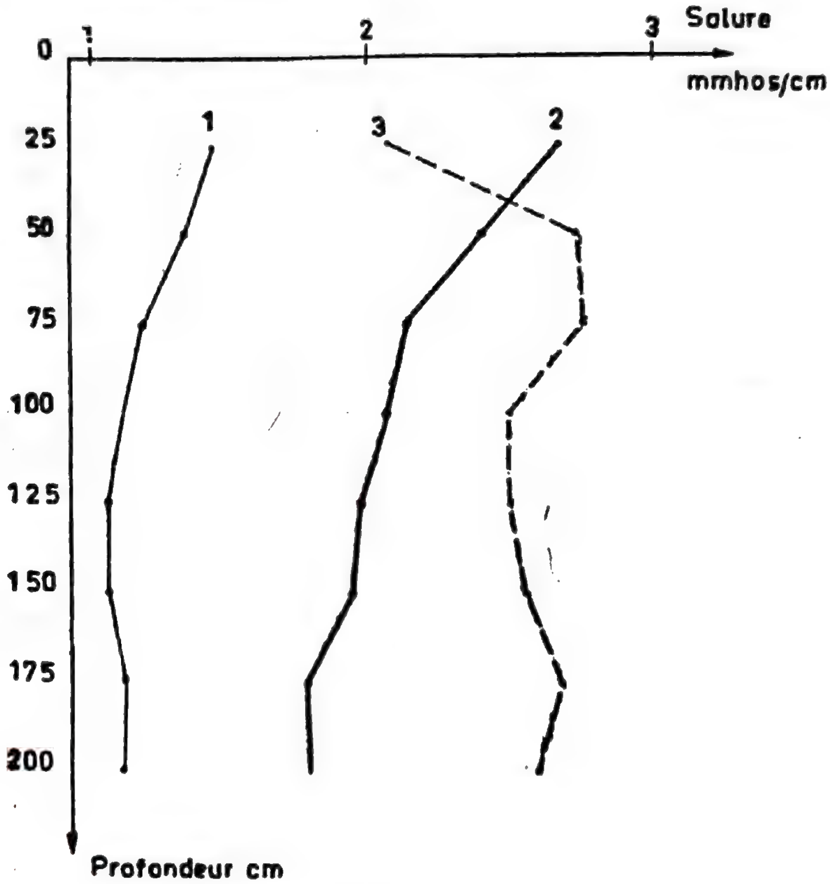

Fig. 1. Évolution de la salure en profondeur :
1 — profil de salure au départ; *2* — profil en fin de saison;
3 — profil à la fin de la 2-ème saison.

À la dose ETP la salure des plantes arbustives atteint 3,1 mmhos/cm. Pour les cultures annuelles on note une pointe à 5,5 mmhos/cm sous culture de coton. Mais avec les cultures suivantes la salure est retombée à 4,1—4,5 mmhos/cm.

À la dose ETP-2,5 mm/j la conductivité maximum sous oranger est de 3,7 mmhos/cm, sous olivier 4,2 à 4,5 mmhos/cm, sous cultures annuelles 4,0 à 4,8 mmhos/cm.

À la dose ETP — 5 mm/j ces valeurs sont respectivement 3,1—4,0 à 5,0—3,3 à 3,8 mmhos/cm.

Les pointes de salure les plus élevées s'observent donc dans le traitement 2 et affectent surtout les oliviers (fig. 2 *b*). En fait ce dernier point s'explique peut être par le mode d'irrigation. Au lieu de répartir l'eau sur toute la surface de la parcelle élémentaire comme c'est le cas pour l'oranger et les cultures annuelles, l'olivier est irrigué en cuvette dont la surface est

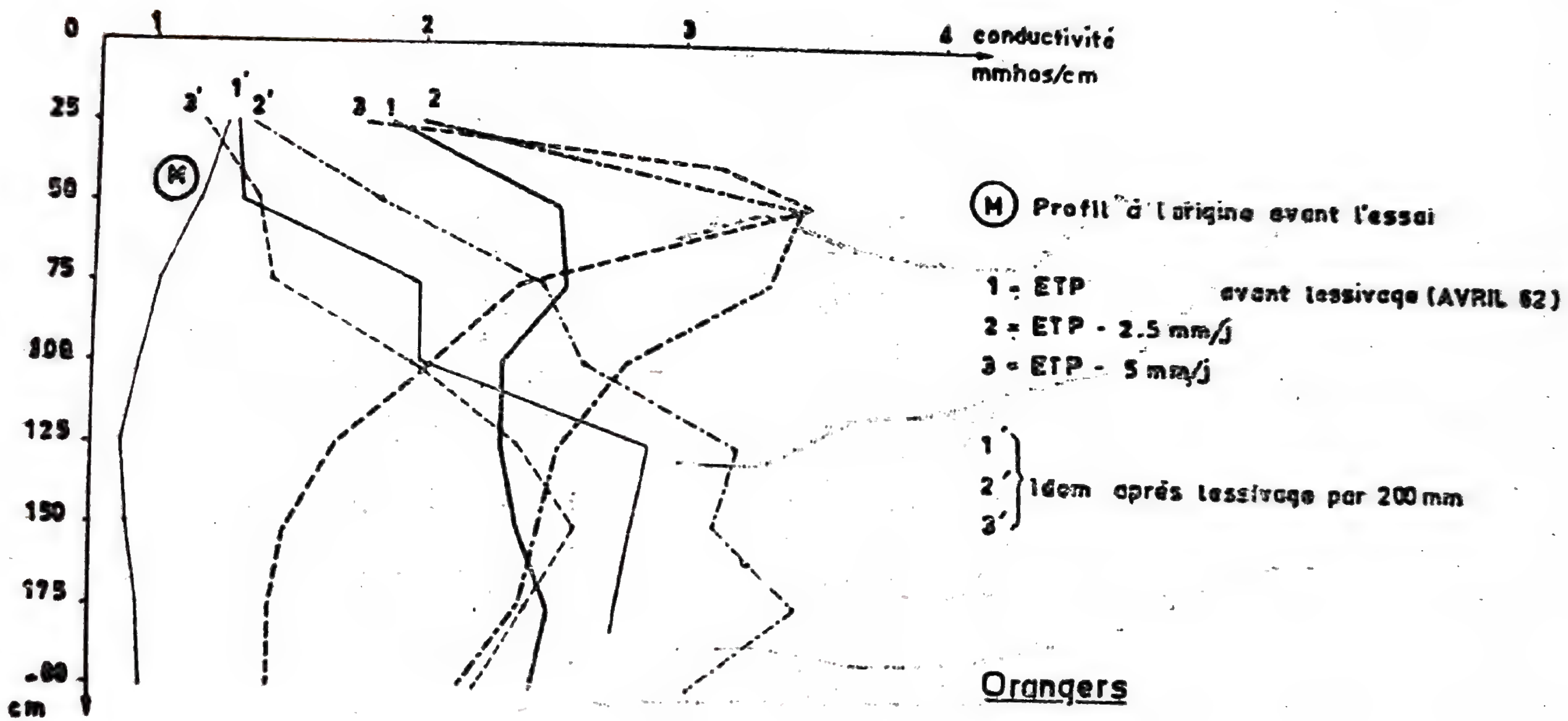

Fig. 2 *a*. Répartition de la salure dans un sol irrigué à l'eau salée.

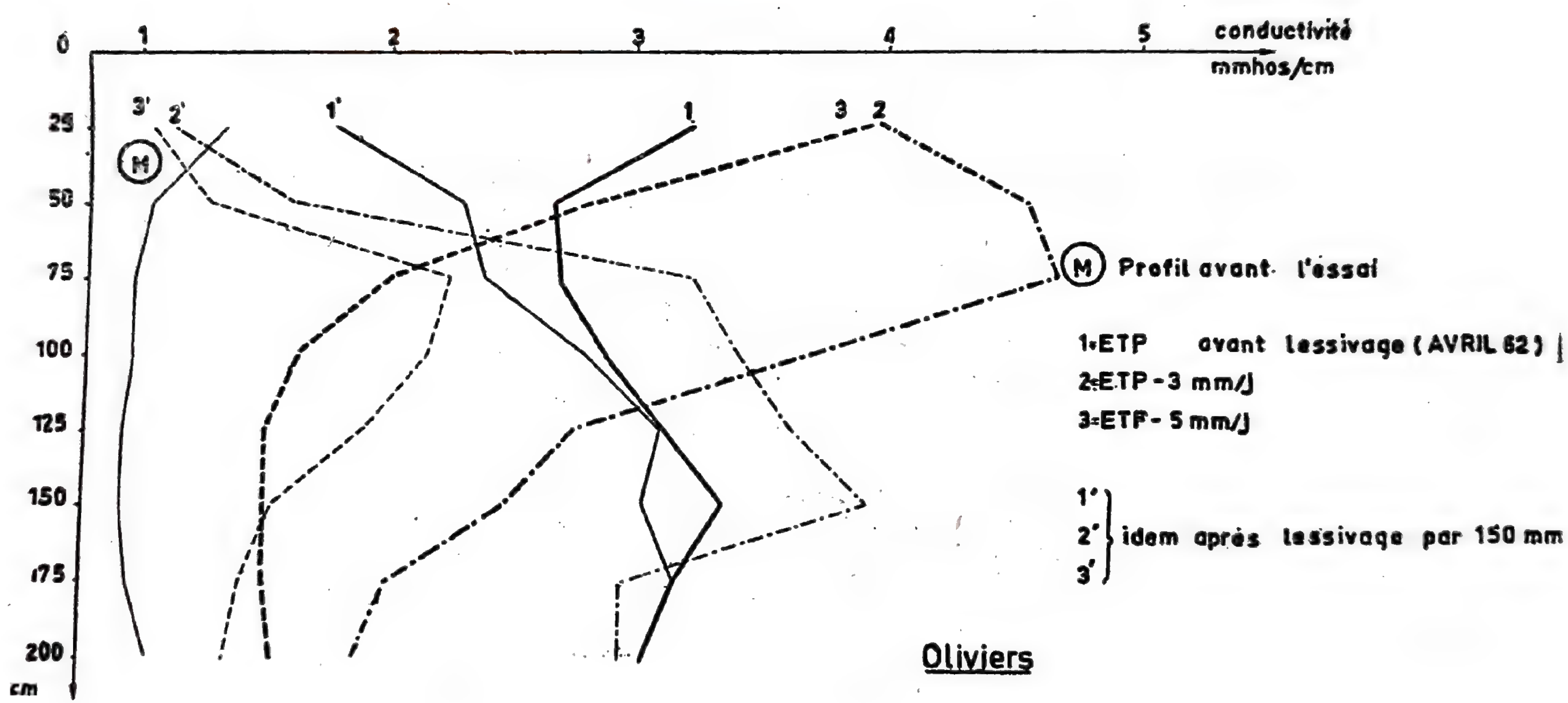

Fig. 2 *b*. Répartition de la salure dans un sol irrigué à l'eau salée.

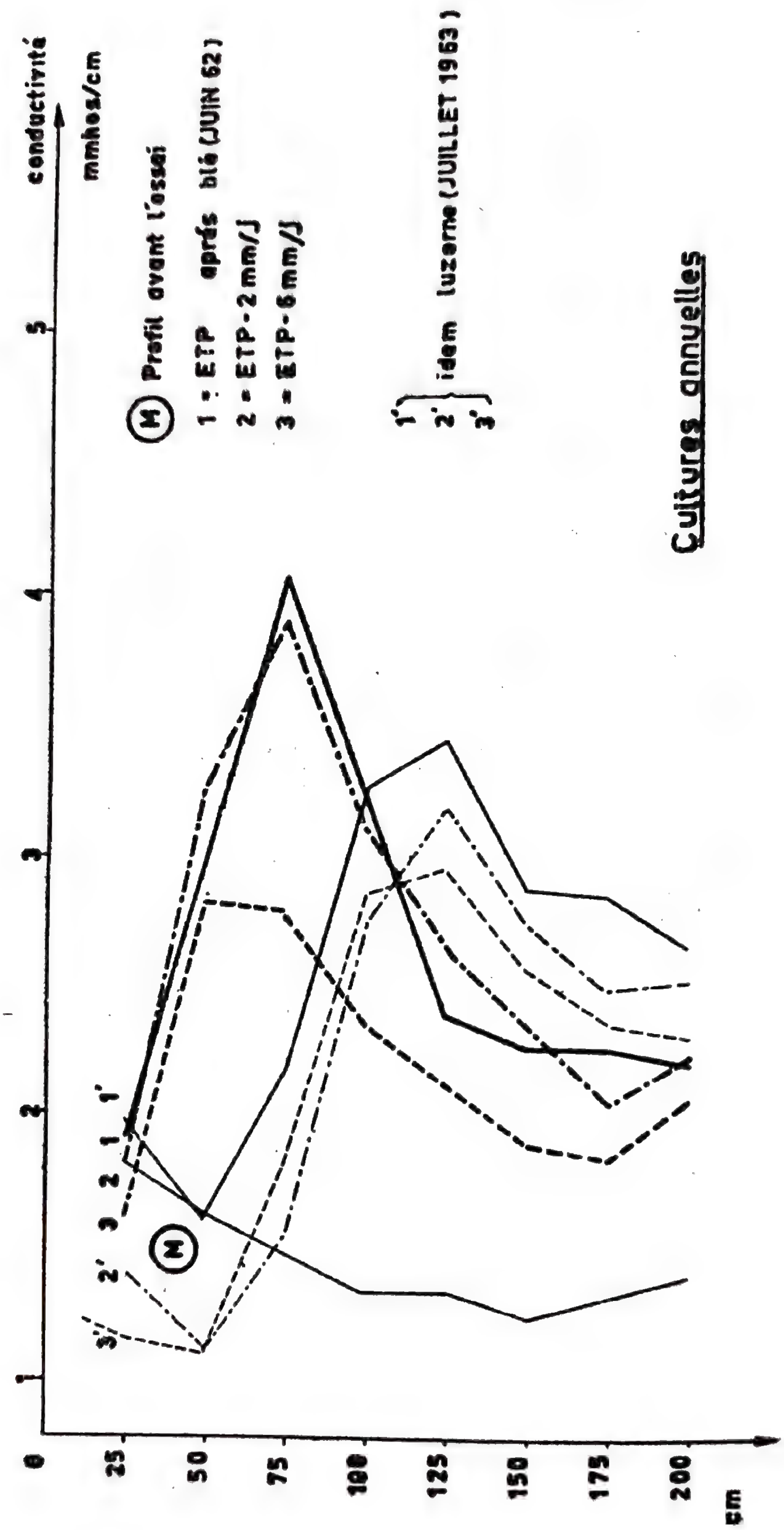

Fig. 2 c. Répartition de la salure dans un sol irrigué à l'eau salée.

le tiers d'une parcelle élémentaire. La diffusion latérale étant faible les oliviers ont donc reçu des doses plus élevées que les orangers.

Par suite de la grande plasticité de l'olivier vis-à-vis des conditions d'alimentation en eau, on peut admettre que les arbres ont entièrement utilisé les doses faibles ou moyennes ce qui explique que humidité et salure aient été stoppées aux mêmes profondeurs que dans la culture d'oranger. Seule la dose la plus forte concentrée sur une surface plus petite n'est pas entièrement consommée et entraîne les sels solubles à une profondeur un peu plus grande.

5. En raison du déficit pluviométrique des années 1961 et 1962, on a reconstitué en fin 1962 une partie des réserves en eau du sol par des irrigations massives à l'eau douce. Sous oranger un apport de 200 mm a fait descendre la pointe de salure de 50 cm environ. Sous olivier où l'apport n'a été que de 150 mm mais toujours sur une surface réduite, le maximum de salure est descendu de 75 cm.

La reprise des irrigations différentielles en 1963 a amorcé la reconstitution d'une nouvelle pointe de salure dans la zône précédemment lessivée.

6. On a essayé sans succès de dresser un bilan des sels apportés et des sels accumulés dans le sol. Les mesures sont trop imprécises pour obtenir un bilan équilibré. Par ailleurs, l'examen des profils de salure montre que à la dose ETP il y a migration de sel au delà de 2 m de profondeur. À dose d'irrigation réduite l'accroissement de salure à 2 m et au delà est plus faible mais non négligeable. Or, l'étude de la variation des réserves d'eau à cette profondeur (Damagnez et De Villele) montre que l'humidité est sensiblement constante et très inférieure à la capacité au champ. Il faut donc admettre une migration du sel en profondeur sous l'influence d'un autre gradient, un gradient thermique probablement.

7. L'irrigation à l'eau salée a amorcé un léger phénomène d'alcalisation du sol. Les parcelles d'oliviers qui sont les plus salées ont également les taux les plus élevés de sodium échangeable dans le sol. Sous oranger l'alcalisation est moins importante. Les traitements à forte dose donnent les valeurs les plus élevées :

— sous oliviers maximum 10 à 12% en surface et jusqu'à 0,75 m
minimum 8% à partir de 1,50 m ;

— sous orangers maximum 10% vers 0,75 m
minimum 6% à partir de 1,50 m.

Les doses les plus faibles n'ont modifié l'alcalisation que dans l'horizon superficiel.

La courbe des variations d'alcalisation avec la profondeur se superpose au profil de salure.

Le lessivage des sels effectué en 1963-1964 a fait descendre la salure en profondeur mais n'a pas modifié l'alcalisation. Ce phénomène est donc plus lent à se produire.

CONCLUSION

1. Au bout de trois ans l'utilisation d'une eau à 2,68 g/l pour l'irrigation n'a pas provoqué une salure élevée du sol. Il se produit néanmoins une concentration plus élevée du sel dans la zône d'exploration des racines qui coïncide du reste avec la profondeur maximum de pénétration du front humide.

2. L'utilisation de l'eau salée provoque une réelle diminution de rendement pour toutes les cultures à l'exception du coton et de l'olivier qui voient leurs rendements augmenter par irrigation à l'eau salée :

— maïs : réduction de 6 à 10% non significative,
— blé : augmentation de récolte de 35% environ,
— luzerne : 11 à 12% de réduction,

Tableau 1

Doses d'irrigation et rendements obtenus par irrigation à l'eau salée

		1	2	3
		ETP	ETP-2 mm/jour	ETP-5 mm/jour
Orangers				
1960	Irrigation	805 mm	445 mm	147 mm
	Rendements	12,1 Kg/arbre	12,6	10,4
1961	Irrigation	945 mm	525 mm	180
	Rendements	41,4 kg/arbre	39,7	29,5
1962	Irrigation	805 mm	390	0
	Rendements	11,8 kg/arbre	8,6	8,1
1963	Irrigation	775 mm	355	140
	Rendements	35,7 kg/arbre	37,5	33,7
Oliviers				
1960	Irrigation	733 mm	367	143
	Rendements	1,24 kg/arbre	0,97	1,50
1961	Irrigation	860 mm	435	164
	Rendements	57,4 kg/arbre	50,6	36,0
1962	Irrigation	770 mm	294 mm	0
	Rendements	saisonnement	saisonnement	saisonnement
1963	Irrigation	850 mm	330 mm	150 mm
	Rendements	Récolte encore sur l'arbre		

		ETP	ETP-1 mm/j	ETP-2 mm/j	ETP-4mm/j	ETP-6mm/j
Maïs 1960	Irrigation	400 mm	336	276	146	21
	Rendements	76,8qu/ha	73,1	72,2	49,3	20,7
Coton 1961	Irrigation	1.160 mm	1.071	1.014	876	747
	Rendements	25,0 qu/ha	24,8	21,4	18,2	16,0
Blé 1962	Irrigation	90 mm	40	0	0	0
	Rendements	35 qu/ha	35	35	35	35
Luzerne 1962—1963	Irrigation	1.245 mm	1.090	955	755	600
	Rendements (matière sèche)	20 qu/ha	19,6	17,8	15,2	12,4

— oranger: 25 à 30% de réduction,
— coton: augmentation de 15 à 20%,
— olivier: augmentation de récolte de 23% en 1961 augmentation du rendement en huile.

Il est encore trop tôt pour déceler une interaction entre la salure et les doses d'irrigation. Pour l'instant les réductions de rendement sont les mêmes pour tous les traitements. Cependant, au simple examen des profils de salure, le traitement ETP — 2 mm/j semble le plus dangereux car il provoque une accumulation importante de sel et un début d'alcalisation dans la zône radiculaire. La salure moyenne dans les parcelles arrosées aux doses ETP — 2 mm/j est systématiquement plus élevée, alors que, au point de vue économique, cette dose semble la plus intéressante.

3. On peut opérer un lessivage des sels solubles du sol. Le lessivage par les pluies d'hiver est évidemment le meilleur procédé. Mais seules les grosses pluies provoquent une diminution sensible de salure. Ce résultat est fonction de l'état de dessication du sol. Plus un sol est sec, plus il se réhumecte difficilement et plus le lessivage est réduit. Lorsque la pluviométrie est insuffisante il faut lessiver a l'eau salée. Les apports massifs d'eau de lessivage augmentent la salure globale du sol mais font disparaître, la pointe de salure. Il semble plus efficace dans ces conditions d'effectuer le lessivage en période hivernale, au moment où le sol est déjà humide et où les besoins en eau des cultures sont plus faibles laissant ainsi un excédent d'eau disponible (tableau 1).

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RÉSUMÉ

En Tunisie, où les ressources en eau d'irrigation sont pauvres et généralement chargées en sel, on a réalisé un essai comparatif d'irrigation à l'eau salée (2,7 g/l) et à l'eau douce sur un sol limono-argileux profond et non salé.

On a constaté en trois ans d'expérimentation que:

— la répartition du sel est assez semblable dans les différents essais. Cette répartition est caractérisée par un maximum de salure au niveau du front d'humectation.

— la salure du sol est d'autant plus importante qu'on apporte plus d'eau.

— le maximum de salure est peu important: 3 à 4 mmhos/cm.

— pour l'instant, les variations de rendement sont davantage liées à la dose d'irrigation qu'à la salure.

SUMMARY

A comparative test between brackish water irrigation (2.7 g/l) and fresh water irrigation on a deep, non-saline clay loam, was carried out in Tunisia, where the irrigation water resources are poor and usually saline.

After three years of experimentation, the following conclusions were drawn:

— salt distribution is rather similar in the various tests. The distribution is characterized by a maximum salinity at the level of the wetting front;

— the greater the water supply, the higher the soil salinity;

— the maximum salinity is of little importance: 3 to 4 mmhos/cm;

— for the time being, yield variations are related more to the irrigation dose than to salinity.

ZUSAMMENFASSUNG

In Tunesien, wo die Hilfsquellen an Bewässerungswasser dürftig und im allgemeinen salzhaltig sind, wurde ein Bewässerungs-Vergleichsversuch mit salzhaltigem Wasser (2,7 gl/) und mit Süsswasser, auf einem tiefen und nicht-salzigen schluffig-tonigen Boden durchgeführt.

Während dreier Versuchsjahre wurde folgendes festgestellt:

— die Verteilung des Salzes ist bei den verschiedenen Versuchen eine ziemlich ähnliche. Diese Verteilung ist durch ein Maximum der Salzhaltigkeit auf der Höhe der Benetzungsfront gekennzeichnet.

— die Bodensalzigkeit ist um so bedeutender je mehr Wasser zugeführt wird.

Das Maximum an Salzigkeit ist unbedeutend: 3 bis 4 mmhos/cm.

— derzeit stehen die Ertragsschwankungen mehr mit der Bewässerungsdosis als mit der Salzhaltigkeit im Zusammenhang.

DISCUSSION

M. VAN DER MOLEN (Hollande): Comment expliquez-vous les différentes formes d'accumulation de sel que vous avez observées dans le sol.

J. P. COINTEPAS: Dans le traitement à dose maximum le sel est entrainé en profondeur au dessous de 2 m (profondeur limite des sondages) par suite du mouvement de l'eau en profondeur. Pour les autres traitements le mouvement de l'eau est très réduit et le sel se concentre à faible profondeur, pratiquement dans la zone explorée par les racines.

M. CĂDERE (R. P. R.): Les études concernant la salure ne tiennent pas compte de l'effet de la nappe.

J. P. COINTEPAS: Dans l'essai décrit ici la nappe étant profonde, 8 m. environ, on a pu constater au cours de l'essai qu'elle n'avait aucune action.

Il existe des zones où la nappe phréatique plus ou moins en charge peut avoir une action qui se fait sentir jusqu'à la surface. Mais ce n'est pas le cas ici.

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THE INFLUENCE OF IRRIGATION WATER OF HIGH SODIUM CARBONATE CONTENT ON SOILS

I. SZABOLCS [1]

The effect of irrigation waters on soils gains an ever growing importance in our days. With the development of irrigation farming and the increased extension of irrigated areas the necessity to utilize waters of more or less significant salt content for irrigation purposes arises more and more frequently. It is well known that the irrigation water and its salt content may exercise two different influences in irrigation farming. One of these influences is the immediate effect of salts on plants while the other is the effect of irrigation water salt content on the soil. As a rule, the first effect may become injurious when the irrigation water contains such a large amount of salt that the damaging influence is exercised in the form of increased osmotic pressure of the solution or large-scale accumulation of some substance detrimental to plants. Such effect is caused as a rule by an extessive amount of disolved salt and it appears already in the year of irrigation by damaging or even killing the vegetation. The other effect needs a longer time to influence the characters of the soil, changing by implication the physical, chemical and other soil features and finally the soil fertility itself. For such an unfavourable effect on the characters of the soil, a comparatively lower amount of water soluble salts is sufficient.

It is well known that among salts disadvantageous for plant and soil the sodium salts mainly deserve attention. Among these, soda (sodium carbonate) occupies a particular place because it is not only injurious to plants in the same concentration as most of the other sodium salts but it also has bad effects on soil characters.

It should be noted of course that in some cases it is unavoidable to use waters containing more or less soda for irrigation. This applies particularly to areas where the natural irrigation waters contain sodium carbonates. This is the case especially when irrigation is carried out with ground waters or when drainage waters find their way into the irrigation system.

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In the practice of irrigation in Hungary the presence of soda in the irrigation water was considered to be inadmissible. Even the present irrigation norms tolerate sodium carbonates only to a limit of 10 mg/l.

Considering, that in the irrigation practice, the soda content of the waters is higher than the above mentioned limit, four year experiments have been carried out in order to establish the use for irrigation of waters of different sodium carbonate contents.

The experiments were set up with rice culture and irrigation waters of different chemical composition were used for each plot.

The experimental design was as follows:

I.Rice flooded with water of natural composition.

II. Rice flooded once with irrigation water of 400 mg/l (i.e. 400 ppm) sodium carbonate content.

III. Rice flooded once with irrigation water of 1 000 ppm sodium carbonate content.

IV. Rice flooded with water of natural composition.

V. Rice flooded twice with irrigation water of 200 ppm sodium carbonate content.

VI. Rice flooded twice with irrigation water of 500 ppm sodium carbonate content.

Thus plots No. II and III, received in one, while plots No. V, and VI, in two dosage rates the irrigation water of 400 ppm and/or 1,000 ppm sodium carbonate content. Plots No. 1 and IV, were irrigated with natural water and thus served as a control. The total amount of irrigation water applied to the plots during the vegetation period was 9,200 m^3 per hectare.

The experiments were conducted from 1959 to 1962 during four vegetation periods. Both the soil and the irrigation water were sampled in every experimental year to establish the changes that occured as an effect of irrigation.

Between the irrigation water and the sodium carbonates incorporated in the soil, an interaction arose and thus even in the case of irrigation waters with which a significant amount of sodium carbonates was introduced, the sodium carbonate content subsequently diminished as an exchange reaction took place between the soil colloids and the irrigation water of sodium carbonate content according to the following equation:

$$R_2Ca + 2Na^+ + CO_3^{--} \rightleftarrows 2RNa + CaCO_3$$

As a matter of fact, in basic media the reaction followed the direction of the upper arrow, since it was promoted by calcium and partly magnesium compounds precipitated in an insoluble form. These analyses are illustrated by table 1.

In table 1 a comparison is made between the original irrigation water and the water enriched with 1,000 ppm sodium carbonate after penetrating the soil. It clearly appears from the data of the table that a considerable material — both as regards the total amount of salts and that of the sodium carbonates — came from the irrigation water into the soil. Along

Table 1

Analysis of Irrigation Waters after Flooding

Treatment	Total salt g/l	Ca^{++}	Mg^{++}	Na^{+}	HCO_3	Na_2CO_3
		p.p.m.				
Original irrigation water	0.22	1.58	1.15	1.04	2.20	—
Original irrigation water + 1000 ppm Na_2CO_3	0.97	1.07	0.56	15.20	13.50	1.24

with the increase of the sodium carbonates in the water, the amount of the calcium and magnesium ions substantially diminished which accounts for the alkalisation of the water.

It is a matter of course that beyond the data presented in the table the changes in the chemical composition of the waters used for irrigation were further analysed in due time and it was found that in the meantime the water became more concentrated to a certain extent in the period of evaporation and it was diluted after addition of pure irrigation water.

As to the changes occuring in the soil, sampling was also performed regularly and analyses were carried out. Some characteristic analyses are reported in table 2, where the changes of the salt contents in the experimental plots are demonstrated by a comparison of the values found at the outset of the test with those obtained at the end of the period. Examination of the experimental data reveals that the salt content and the pH value increased, to a more limited extent, also in those plots where irrigation water of natural composition, that is, of favourable effect was used.

This appears from the analytical data related to plots I and IV. In those plots, however, where water of a certain sodium carbonate content was used the pH value and the alkalinity of the soils increased to a far greater extent. Thus in plots No. II and III, a remarkable increase in the pH values can be observed and the same trend was recognized in connection with the change in the amount of sodium hydrocarbonate.

The increase of sodium ions, as measured in the aqueous soil extract, follows a similar trend.

Similar changes are displayed by the data of plots No. V and VI. Though from table 2 it appears that upon the effect of the soda-treated irrigation water, the amount of the soluble salts did not essentially increase on the plots involved, the alkalinity of the medium and the amount of the water soluble sodium salts were found to be definitely higher. From all this it may be concluded that the sodium carbonates added to the irrigation water in such a high concentration do not accumulate in the soil in the form of soluble salts but they get bound on the colloid particles of the soil in an exchangeable form. This finding is supported by determinations of the exchangeable cations of the soil.

These determinations were equally carried out on all plots at the outset of the experiment and at its end after four years.

Table 2

Analysis of the Soils of the Experimental Plot by 1:5 Aquenus Extracts

Plot number and date	Depth cm	pH	Total salt per cent	$NaHCO_3$	Total HCO_3	Na^+
				mg. equ.		
I. 1959	1—10	7.3	0.076	0.87	1.01	0.64
	80—100	7.1	0.127	0.47	0.84	0.74
1962	0—10	7.6	0.155	1.47	1.53	0.34
	80—100	7.5	0.170	1.79	1.98	1.34
II. 1959	0—10	7.1	0.114	0.43	0.73	0.30
	80—100	7.4	0.225	2.39	2.48	3.24
1962	0—10	7.4	0.190	1.24	1.36	0.41
	80—100	7.9	0.245	2.45	2.48	2.34
III. 1959	0—10	7.0	0.116	0.39	0.77	0.45
	80—100	7.8	0.281	2.36	2.38	4.14
1962	0—10	7.9	0.165	1.47	1.53	1.13
	80—100	8.2	0.340	3.22	3.37	3.82
IV. 1959	0—10	6.7	0.123	0.48	0.60	0.32
	80—100	7.1	0.279	1.49	0.59	3.82
1962	0—10	6.8	0.110	1.59	1.68	0.34
	80—100	8.1	0.250	2.72	3.63	3.82
V. 1959	0—10	7.2	0.198	0.46	1.07	0.87
	80—100	7.2	1.190	0.46	0.95	1.04
1962	0—10	7.9	0.060	1.18	1.53	0.47
	80—100	8.4	0.260	3.28	3.46	3.65
VI. 1959	0—10	6.9	0.900	0.52	0.95	0.47
	80—100	7.2	0.350	0.66	0.99	3.92
1962	0—10	7.8	0.110	1.12	1.27	0.73
	80—100	8.0	0.200	2.16	2.21	2.69

The results of the above mentioned analyses are condensed in table 3 where the amount of the exchangeable sodium ions is reported as a per cent of the amount of the total exchangeable cations.

From the data of table 3 it clearly appears that in plots No. 1 and IV which were given irrigation water of natural quality and served, as a control, the relative amount of the exchangeable sodium underwent substantial change in the course of the four experimental years. As a contrast, the per cent value of the exchangeable sodium remarkably increased in the upper horizon of all plots treated with water of sodium carbonate content. This increase is comparatively lower in the case of plot No. II and higher in the case of plots No. III, V and VI.

Both the data of table 2 and 3, unequivocally show that in all cases where the same amount of sodium carbonate was added with one operation to the irrigation water, the increase in the alkalinity of the soil was lower as compared with the treatment where the same amount was added to the irrigation water in two portions. This appears also from the quantitative

Table 3

Exchangeable Sodium as a Percentage of the S Value

Plot number	Depth of horizon, cm	1959	1962
I	0—10	2.26	2.02
	10—20	1.83	1.68
II	0—10	1.86	2.76
	10—20	3.11	2.03
III	0—10	2.09	4.00
	10—20	2.48	6.06
IV	0—10	1.78	1.81
	10—20	3.92	4.53
V	0—10	2.42	4.14
	10—20	1.82	5.33
VI	0—10	1.55	3.88
	10—20	1.50	3.35

analysis of the amount of the exchangeable sodium as well as from the analysis of the hydrocarbonate and sodium ions of the soil. Hence it may be concluded that higher amounts of sodium carbonates can be tolerated in the irrigation water when they occur only periodically and do not form a constant component of the irrigation water. Naturally, the data presented in tables 2 and 3 demonstrate that the exchangeable sodium and/or soluble salt content of the soil did not reach such values as the soil could be termed an alkali or saline soil. Since, however, the tables clearly exhibit the increasing trend, there is no doubt that when irrigation is continued for a longer period with water of sodium carbonate content, the soil becomes alkaline or saline.

That this did not actually occur in the course of the four experimental years is partly due to the fact that irrigation with water of sodium carbonate content has been carried out only in a small portion of all cases as compared with the use of natural irrigation water of good quality.

Naturally, the chemical composition of the soil and the presence of soluble salts, particularly of calcium salts in the soil may largely influence the limit set to sodium carbonate contents in the irrigation water. When the soil contains soluble calcium salts to a more considerable extent, higher amounts of sodium carbonate can be tolerated in the irrigation water because these carbonates entering into reaction with the soluble calcium compounds of the soil give rise to neutralisation of the harmful effects of the sodium carbonates.

Regular soil analyses and regular analyses of the irrigation waters are absolutely necessary in order to establish the amount of sodium carbonates which can be tolerated regularly or periodically in the irrigation water in any well defined case.

SUMMARY

The subject of the experiments was to study the periodical influence of irrigation waters with various sodium carbonate contents on soil properties and to determine the limit of sodium carbonate content that may be tolerated in waters used for irrigation.

From the obtained data the following conclusions may be drawn:

1. Irrigation waters with sodium carbonate content increase soil alkalinity and develop the absorbtion rates of sodium ions on soil colloids from the soil solution.

Due to the conditions favourable for sodium, absorbtion during the comparatively short experimental period, a measurable increase in the exchangeable sodium content of the soil could be demonstrated.

2. The exchange equilibrium between soil and water with soda content is established in a short time, as indicated by the fact that in the irrigation water immediately after flooding a substantially lower sodium ion concentration was measured than could be theoretically expected by the amount of soda applied. This points also to the fact that sodium carbonate occuring periodically in the irrigation water is fixed in a short time. The rate of exchange depends on the chemical properties of both soil and water.

3. The increasing alkalinity of soils makes advantageous conditions for the further adsorbtion of sodium ions.

4. From the preceeding it follows that if the irrigation water contains soda only periodically, the limit of the water sodium carbonate concentration can be higher than if soda is a constant chemical component of the water.

5. During the four year treatment the flooding water contained soda only periodically and the ratio between natural water with free sodium carbonate content and the water with soda content was 8.2 : 1 or 7.2 : 2, respectively. The increase in the amount of the exchangeable sodium of the soil was exactly measured but it was not so considerable as it could have been, due to the morphological characters of alkali/Szik/ soil.

6. It may be also concluded that if there are water soluble calcium salts (e.g. gypsum) in the soil, the increase in the quantity of the sodium carbonate content of the irrigation water depends on their amount.

RÉSUMÉ

Le sujet des expériences a été d'étudier l'influence périodique sur le sol des eaux d'irrigation chargées de diverses quantités de carbonate de sodium et de déterminer la limite de tolérance de la teneur en carbonate de sodium dans les eaux d'irrigation.

L'on peut tirer les conclusions suivantes à partir des données obtenues.

1. Les eaux d'irrigation contenant du carbonate de sodium augmentent l'alcalinité des sols et font montrer la ration des ions de sodium adsorbés par les colloïdes du sol.

À cause des conditions favorables pour l'adsorption du sodium, l'on peut démontrer à la fin de cette période expérimentale relativement courte, une augmentation mesurable de la teneur en soude échangeable des sols.

2. L'équilibre d'échange entre le sol et l'eau contenant du carbonate de sodium s'effectue dans un laps de temps court, ce qui est indiqué par le fait que la concentration des ions de sodium dans l'eau d'irrigation est considérablement plus faible que celle à laquelle on pouvait s'attendre théoriquement en partant de la quantité de carbonate de sodium appliquée. Cela est aussi confirmé par le fait que le carbonate de sodium qui se trouve périodiquement dans les eaux d'irrigation est fixé rapidement. L'allure de l'échange dépend des propriétés chimiques du sol et de l'eau.

3. L'alcalinité croissante des sols rend les conditions favorables pour une adsorption ultérieure d'ions de sodium.

4. De ce qui précède il s'ensuit que si l'eau d'irrigation ne contient pas du carbonate de sodium, cette quantité peut être plus élevée que si la soude est un composant constant de l'eau.

5. Pendant les quatre années du traitement l'eau d'irrigation ne contenait du carbonate de sodium que périodiquement et le rapport de l'eau fluviale exemple de soude avec l'eau en contenant, a été 8,2 : 1 ou 7,2 : 2, respectivement. L'on a dosé exactement la quantité d'ions de sodium dans les sols mais celle-ci n'était pas d'ordre de produire les caractères morphologiques d'un sol à alcali (szik).

6. L'on peut aussi conclure à ce que s'il y a dans le sol des sels de calcium solubles dans l'eau (p. ex. du gypse), l'accroissement de la quantité de carbonate de sodium dans l'eau d'irrigation dépend de leur quantité.

ZUSAMMENFASSUNG

Der Zweck der Versuche war, den periodischen Einfluss der Bewässerungswasser von verschiedenem Natriumkarbonatgehalt auf die Bodeneigenschaften zu studieren, und die Grenze des Natriumkarbonatgehaltes welcher in den zur Bewässerung verwandten Wassern noch toleriert werden kann zu bestimmen. Aus den erhaltenen Angaben können folgende Schlussfolgerungen gezogen werden:

1. Sodahaltige Bewässerungswasser erhöhen die Bodenalkalität und fördern den Umfang der Adsorption der Natriumionen an Bodenkolloiden aus der Bodenlösung.

Dank den für die Natriumadsorption günstigen Bedingungen konnte während der veshältnismässig kurzen Versuchsperiode eine messbare Zunahme im austauschbaren Natriumgehalt des Bodens nachgewiesen werden.

2. Das Austauschgleichgewicht zwischen Boden und sodahaltigem Wasser wird in kurzer Zeit hergestellt; hierfür spricht die Tatsache, dass im Bewässerungswasser, unmittelbar nach der Berieselung, eine wesentlich niedrigere Natriumionenkonzentration festgestellt wurde als es theoretisch, nach der Menge der verwendeten Soda, zu erwarten gewesen wäre. Dies weist auch auf die Tatsache hin, dass das im Bewässerungswasser periodisch vorkommende Natriumkarbonat in kurzer Zeit fixiert wird. Das Ausmass des Austausches hängt von den chemischen Eigenschaften von Boden und Wasser ab.

3. Höhere Alkalität der Böden schafft günstige Bedingungen für die weitere Adsorption von Natriumionen.

4. Aus diesen Ausführungen folgt, dass, wenn das Bewässerungswasser nur periodisch Soda enthält, die Grenze der Natriumkarbonatkonzentration des Wassers höher liegen kann als in jenem Falle, in welchem Soda einen ständigen chemischen Bestandteil des Wassers bildet.

5. Während der vierjährigen Behandlung hat das Berieselungswasser nur periodisch Soda enthalten und das Verhältnis des natürlichen, natriumkarbonatfreien Wassers zum Wasser mit Sodagehalt war 8,2 : 1 bzw. 7,2 : 2. Die Zunahme des austauschbaren Natriumgehaltes der Böden wurde genau bestimmt, war aber nicht so bedeutend als es den morphologischen Merkmalen des Alkali (Szik)-Bodens entsprechend gewesen wäre.

6. Es kann weiter gefolgert werden, dass wenn der Boden wasserlösliche Kalziumsalze (z.B.Gips) enthält, die Zunahme des Natriumkarbonatgehaltes im Berieselungswasser von deren Menge abhängt.

DISCUSSION

R. CĂDERE (R.P.R.). On peut discuter ces deux problèmes ensemble: l'effet des irrigations du point de vue de la chimisation du sol par les eaux de surface et par l'effet de l'action des eaux souterraines (phréatiques et celles sous-pression).

Les problèmes ne peuvent être ni séparés — comme l'a montré partiellement Mme Darab, ni limités à une zone d'investigations jusqu'à une profondeur de 2 m, comme l'a fait M. Cointepas. La chimisation, comme l'a montré le Prof. Szabolcs, doit être rapportée à ce phénomène. Le problème de l'avenir est celui de l'étude de l'effet conjugué de ces deux influences.

A. RUELLAN (France). Par quelle méthode déterminez-vous, dans les eaux d'irrigation, la quantité de carbonate de sodium?

M.S. NIKLEVSKI (Poland). In Hungary were there any experiments done with irrigations and with doses of manures?

Are the experiments done with time of water addition?

P. JANITZKI (U.S.A). Was total balance of extractable Na made? How long were the fields flooded, i.e. how long did the water stay at the surface?

I. SZABOLCS. The determination of Na_2CO_3 was carried out with titration of aqueous extract against phenolphtalein.

The importance of the control of the ground water is high, concerning the danger of secondary alkalization is considerable. In our experiences, however, the experimental fields were closed to places where the ground watertable was deep enough to avoid its direct influence on the salt balance of the upper layers of soils.

The influence of irrigation is well known, as the effect of manure and mineral fertilizers. However, this effect is always concrete, depending on the soils, crops, technics, etc.

In Hungary in several places there are greenhouse and field experiments in connection with the joint application of fertilizers and irrigation.

The total Na^+ is given in table 2.

In the rice water was from May to September; it means about five months long.

REGULATION OF THE SALT REGIME IN SOILS UNDER IRRIGATION

I. S. RABOCHEV [1]

A thorough study has been made in Central Asia of intensive irrigation farming in general and of cotton growing in particular. Based on advanced theory and practice, the Soviet farmer has obtained the world's highest yields of cotton. They range from 21 to 22 double cwt per ha, for raw cotton, and from 7 to 7,5 double cwt per ha, for cotton fibre. Such bumper crops would be impossible without high fertilisation, improved tillage, and using the most up-to-date machinery for soil management and irrigation.

To-day in Central Asia some 4,500,000 ha of land are irrigated. Half of this land is under cotton cultivation accounting for 70 per cent of the total income from agriculture.

The irrigated and newly-developed lands depend for their efficiency on reclamation practices such as surface levelling (250—1,500 m^3/ha), leaching (3,000—50,000 m^3/ha) horizontal drainage (10—75 m/ha), and vertical drainage (0.1—1.0 m/ha). According to the specified, requirements the total expenditure for levelling, drainage, and leaching should vary from 133 to 967 roubles per ha.

Soils regarding their irrigation possibility	Expenditure per ha, roubles	Correlations in units
Easy	133—305	1.0—2.3
Medium	352—439	2.7—3.3
Difficult	482—638	3.6—4.8
Very difficult	763—967	5.7—7.2

As a general rule, land has to be first reclaimed and then used, considering that irrigation will not always be a profitable entreprise. In this, one should be guided not only by economic considerations, but also by such soil formation factors as the potential of fertility, the degree and nature of salinity, the regime and sources of ground-water flow etc. Desert-complex

1 Academy of Sciences, Ashkhabad, USSR.

soils in Turkmenia represent 5, 570,000 ha of the total 14,300,000 ha available for irrigation in all Central Asia. Takyrs and takyr-like soils account for 63 per cent. In addition to the chloride and sulphate-chloride solonchaks of the Amu-Darya delta, they make the task of irrigation extremely difficult. Meadow and serozem-meadow soils make 14 per cent, serozems 11 per cent, solonchaks and soddy-alluvial soils 12 per cent, of the total land available for irrigation.

Today, Turkmenia irrigates a total of 500,000 ha, of which 200,000 ha have recently been irrigated. The first 800 km of the Kara-Kum canal have just been completed from the Amu-Darya river to the Kopet-Dag foothills. This will bring the area of irrigated land to 300,000 ha and then to 1,000,000 ha, i.e. for a total of some 1,500,000 ha.

Over half of the newly-irrigated area consists of highly productive serozems, serozem-meadow, meadow, and takyr-like soils, though they may differ in salinity, while highly saline soils represent half of the total land of Turkmenia.

Table 1

Accumulation of salts in waters and soils of different natural zones

Zone	Ground waters g/l	Upper solonchak layers total, per cent	Salts occurring in solonchaks
Forest. steppe	1—3	0.5—1.0	Na_2CO_3, Na_2SO_4, Na_2SiO_3
Steppe	50—100	2—3	Na_2SO_4, $NaCl$, Na_2CO_3
Arid steppe	100—150	5—8	$NaCl$, Na_2SO_4, $CaSO_4$, $MgSO_4$
Desert	200—220	15—25	$NaCl$, $NaNO_3$, $MgCl_2$, $MgSO_4$, $CaSO_4$

According to Kovda, the mineralization of soils and waters depends on the natural zone, in which they occur. The mineralization of soils is determined by the redistribution of salt mass in the soil-forming rocks, subsoil, and surface waters.

According to the redistribution of salts in the geomorphological profile from mountains to plains, three main zones can be distinguished:

1. An immersion zone, in which a subsoil discharge is formed by precipitation, where the ground water occurs at greater depth because of the good drainage. The water is confined to the alluvial cone pebbles where the foothills are well drained with fresh waters without affecting soil formation. The serozem soils of that zone are not mineralised.

2. A zone of rising ground waters, occuring below the first zone and starting from the first alluvial cone, is characteristic of the transition towards the gentle-sloping plains. The drainage of fresh ground water is poor. Most of the sierozem-meadow soils are not mineralised.

3. A zone of scattered and shallow ground waters, the latter being confined to the lower sub-montane plains. The meadow soils of the zone are largely formed by ground waters and are either unevenly mineralized or have a tendency to mineralize. On the wide expanses of Turkmenia plains unique

regularities are observed in the formation and drainage of ground waters and in the redistribution of salts, resulting from regularities of the peculiar geomorphology of alluvial-delta depositions.

The energy of salt accumulation is directly proportional to the evaporation and the mineralization of ground waters, and inversely proportional to their depth. If ground waters under cotton are highly saline, the upper meter of the soil will be considerably mineralized during the year, if the ground waters are as deep as 3 meters.

Table 2

Annual accumulation of salts in the meter layer of soil under cotton cultivation (in dry residue of water extracts)

Depth of groundwater table m	Water discharge m^3/ha	Mineralization of ground waters, g/l					
		1		5		15	
		tons	%	tons	%	tons	%
1	14.3	7.2	0.048	9.7	0.065	23.7	0.158
2	9.7	2.1	0.014	2.5	0.017	23.5	0.157
3	9.3	1.0	0.007	1.4	0.009	21.5	0.144

According to the soil-hydrogeological data collected, both during the formation of natural soils and subsequently, while cropping the irrigated soil, complex processes take place of accumulation and redistribution of salts.

It was shown that the accumulation of salts in the solum takes place, with the ground-water table occurring rather deeply, because of the influx of salt mass by mineralized water and because of the accumulation of river salts round their deltas. This phenomenon is exemplified by the dry deltas of the Murgab, Tejen and the Amu-Darya. Salts are especially abundant in the areas of stagnant subsoil waters, where irrigation farming depends on the low coefficient of land utilization. In the areas under irrigation around the Amu-Darya and Murgab, having a local drainage, the ground waters are demineralized down to 10—30 meters and contain 1—3 g/l of dry residue. Contrary to this, under the solonchaks, occurring either very close to or even in the irrigated soils, at a depth of 30 to over 50 meters, the mineralization of ground waters may be as high as 10 to over 20 g/l.

The uncropped areas were found to accumulate salts. The irrigation water forced the salts either down or sideways, and by capillary force, further into the upper horizons where they formed intraoasis solonchaks. The migration of salts on irrigated lands was mostly downward, while on non-irrigated uncropped lands, upward. Owing to the low coefficient of land utilization (0.2—0.3) the water salt balance of the soils was maintained and the agriculture was possible without drainage.

According to the data obtained in the Central Amu-Darya valley, only part of the total salts of the 2-meter layer migrates into the drains (10—30 per cent), the remainder being eliminated from the aeration zone and low horizons either down or sideways.

The zone of vertical salt exchange may be as deep as 20 to 30 meters, and sometimes 50 to 100 meters, while horizontally the salts migrate up to hundreds of meters. The rate, depth and distance of salt migration depend on the filtration capacity of the soil, the depth of the waterproof horizon, the value of the subsoil-water head and drainage, and last but not least on the intensity of the water supply.

In order to correctly design a reclamation project, one must classify the land in zones according to the difficulty of reclamation and the type of discharge. Such classification must include maps and profiles of salt content in soils, grounds, and in subsoil waters to a depth of 50 m. This use is also made of the data of electrochemical sounding obtained by geophysical methods. In order to determine the mineralization of grounds in the areas of high salt accumulation, one has to bore holes and thus obtain samples of water and ground for chemical analysis. By using hydrochemical maps, profile data, and by calculating the total salt which accumulated in the active salt-exchange strata, it is possible to determine the most effective methods for land reclamation and to select for development those lands which are the least mineralized.

In the daily farming practice on the irrigated lands with stagnant subsoil water, the ground-water table was presumed to rise, from 20—30 m to 1—3 m depth. Reclamation was accordingly aimed at diverting the mineralized water outside the irrigated oases by means of horizontal drainage, rather than preventing its rise.

However, Legostaev, Pankratov, Rabochev, Reshotkina, et al., have recently shown that particular natural conditions and economic factors may sometimes stimulate the adjustment of the moisture salt regime of soils not only by horizontal but also by vertical drainage.

Horizontal drainage may be well advised for hydromorphous conditions with a low mineralization of grounds. For the strata with poor mineralized grounds, vertical drainage should be preferred, by which the mineralized water and hence the salts are pumped into the surface to be disposed of into the catchment basin. Whenever fresh or slightly mineralized ground water is present in the deeper horizons, it may be utilized through vertical drainage not only for irrigation but also for demineralization. In order to demineralize 2—3 m of ground, one has to divert 6,000—9,000 cub. m ha of water annually, and hence to maintain a drainage discharge modulus of 0.2—0.3 l/sec. per ha of drained area for 250—300 days. Given the adequate filtration capacity of soil ground and the adequate rates of irrigation, it is possible to demineralize 10—15 m of ground in 3—5 years, whereas without vertical drainage and with a land utilization coefficient of 0.2—0.3, such demineralization would take dozens of years. Vertical drainage should be recommended for an automorphous regime since it will prevent the rise of ground waters and salts from deep underground, a rise which blocks demineralization by the downward flow of leaching water.

The concentration of salts in soil solution for cotton, alfalfa, sorghum, maize, and other irrigated crops should remain within the following limits (g/l):

Mineralization

	Chlorine	Sulphate
during germination	5—7	7—9
during vegetation	7—9	9—11

The optimum salt regime of soils is maintained by leachings and vegetative irrigations coupled with adequate management. The efficiency of irrigation depends on the correct preparation of soil including levelling and ploughing, as well as on several irrigations instead of one. Each water application should make 0.3—0.4 of the water capacity of the given layer, i.e. some 1,200—1,500 m³/ha. Autumn is the best time for leaching because the evaporation either stops or drops sharply, the ground-water table lies deep, while the soil matures before spring cultivation due to the seepage of gravitation moisture.

The water applications are determined by the salinity, moisture-properties of the soil, the depth of the ground-water table, and by other such factors. According to Astapov, Volobuev, Kovda, Kostyakov, Legostaev, Rabochev et al., the general given leaching norm is as follows:

$$M = 100.\,Hd\left[(B_0 - B) + \frac{S_1 - S_2}{K}\right],$$

where M — leaching norm per m³/ha; H — depth of leached layer; d — volume weight of soil; B_0 — maximum moisture content (per cent by weight); B — minimum moisture content before leaching (per cent by weight); $S_1 - S_2$ — content of salts to be leached out (per cent by weight); S_1 — content before leaching; S_2 — content after leaching; K — coefficient of eliminated salts (tons per m³ of water) depending on physical properties of soils, depth of ground-water table, content and nature of salts, time of leaching, etc.

The leaching norms according to particular conditions range from 1,500—2,000 to 10,000—15,000 m³/ha and may be even higher. With a mean annual drainage modulus of 0.15—0.20 l/s per ha the maximum volume of the drainage water diverted will be 4,700—6,300 m³/ha.

Within one season, when the soil is leached by flood, it is possible to supply 5,000—7,000 m³ of water per ha. Therefore the demineralization of poor saline land may take 2—3 years. Until now, water-soluble, and therefore harmful, salts were eliminated from the topsoil downwards and all the recommendations as to the preparation of land, method and timing of leaching, and intensity of water supply have been correlated with the demineralization of soils by flood and check plots. This method of demineralization is effective for lands where salts are concentrated in the lower solum, such as old-irrigated and deep-mineralized newly-deloped lands. When the salts are distributed otherwise, i.e. when 70—90 per cent of their aeration-zone total occur

in the topsoil, conventional leachings eliminate them into the lower horizons and ground water; they rise back again and thus reduce the leachings to nothing.

In such cases, one should wash the salts from the surface or rinse them off. This is the most suitable in the case of a shallow ground-water table, when the salts are much easier to wash off than to wash in.

Such rinsing the salts off may be done by not too-mineralized drainage water in order to reduce the consumption of leaching water and the accumulation of salts in the ground and subsoil water which might otherwise restore the salinity of soils after leaching.

In our experiment the yield of raw cotton of 15.8 double cwt/ha on a poor mineralized soil increased to 25.3—36.4 double cwt/ha. Similar increases in yield were obtained by collective farms in the Chardjou and Khorezm oases, which produced 24—30 double cwt of cotton per ha due to a whole system of such reclamation practices.

Scientific soil reclamation has already elucidated the basic regularities of the complex dynamics and accumulation of salts in various soils and ground strata. Now, that new multipurpose hydro-projects have been started upon, and vast areas of land have been taken under irrigation, these regularities should be used on a daily basis. At the same time, one must not forget to further improve the regulation of the water-salt regime of soils of each particular reclamation project.

SUMMARY

In Middle Asia, cotton-growing is the main branch of irrigated agriculture. The further expansion of cotton-growing is bound with a growth of arable lands at the expense of saline or potentially saline soils and increase in their fertility.

Desalinization of the 10—15 m layer and the maintainance of a favourable meliorative background by leaching and drainage, is the main question of melioration. The horizontal drainage is effective for areas with a minimum mineralization of ground waters and high salinity of the upper soils layers. For areas with a high salt concentration in the 10—20 m soil layer and ground waters, the vertical drainage is highly profitable.

RÉSUMÉ

Le coton constitue la principale culture agricole en Asie Centrale. Le développement ultérieur de cette culture exige l'extension des terres labourables au dépens des sols salins ou à salinisation potentielle et d'augmenter leur fertilité. La désalinisation de la couche de 10—15 m et le maintien d'un régime favorable à l'aide du lessivage et du drainage constitue le problème principal de l'amélioration. Le drainage horizontal est efficace dans les zones présentant une minéralisation minimum des eaux souterraines et une forte salinisation des couches supérieures. Le drainage vertical est d'une très grande utilité dans les zones caractérisées par une concentration élevée des sels dans la couche de 10—20 m et des eaux souterraines.

ZUSAMMENFASSUNG

In Mittelasien ist die Baumwollkultur der Hauptzweig der bewässerten Landwirtschaft. Die weitere Ausdehnung der Baumwollkultur ist mit der Vermehrung bebaubaren Landes verbunden, dies auf Kosten salziger oder potentiell salziger Böden und der Zunahme ihrer Fruchtbarkeit.

Die Entsalzung der 10—15 m Schicht die Aufrechterhaltung eines günstigen meliorativen Untergrunds durch Auswaschung und Entwässerung, ist das Hauptproblem der Melioration. Die horizontale Entwässerung ist bei solchen Geländen wirksam, die die möglichst geringe Mineralisierung der Grundwasser und einen hohen Salzgehalt der oberen Bodenschichten aufweisen. Bei Flächen mit hoher Salzkonzentration in der 10—20 m Bodenschicht und den Grund ist die vertikale Entwässerung höchst vorteilhaft.

DISCUSSION

PH. CULOT (Belgium). I would have been interesting to know something on the way the figures given for the accumulation of salts by capillary rise of water would vary for soils of other texture, and particularly for clays.

P. JANITZKI (U.S.A.). Calculations of critical groundwater level concern only the total salt concentration of groundwater. One should expect that the presence of different anions (HCO_3^-, SO_4^{--}, Cl^-) would result in different figures for that critical level because of great differences in the solubilities of the various salts.

SALINE SOILS OF YAKUTIA

L. G. ELOVSKAYA [1]

The saline soils of Yakutia chiefly occur in the basin of the middle Lena being confined to the valleys of large rivers and to lacustrine depressions within the boundaries of a paleoalluvial plain. Saline soils here are usually cryogenic meadow-chernozem, chernozem-meadow, and occasionally, meadow-boggy and peaty-boggy drying.

The most widespread are cryogenic meadow-chernozem saline soils. They have a badly frost-cracked surface, rather shallow multiannually frozen parent material, and a thin humus horizon (10—30 cm thick). The upper layer of the humus horizon often bears the signs of solothisation, while its lower layer those of solonetzisation. Commonly, the humus horizon intrudes in pockets into the underlying horizon. It contains 6—12% of humus, 0.2—0.5% of nitrogen, and 0.13—0.23% of phosphorus, its exchange capacity ranging from 15 to 35 me/100 g of soil and the pH of its water extract being 6.7—7.5 (Elovskaya, 1964). Below the humus horizon occurs a porous calcareous horizon which is compacted in solonetzous soil varieties and contains much of calcium and magnesium carbonates (4—10%), and sometimes 5—7% of gypsum in loamy soil varieties. Despite the presence of gypsum, it is in these varieties that the maximum of exchangeable sodium occurs. The water-extract reaction of this horizon is strongly alkaline (pH = 8—9.5). Clearly defined complexes of salinity are also characteristic of cryogenic meadow-chernozem soils. Their soil profile often combines in itself the signs of solonetzisation and salinisation. In the profile of valleys, which have a ridgy-gully topography, the degree and character of salinity are by no means uniform. At the mesorelief, elevations of wide valleys, such as that of river Lena, cryogenic meadow-chernozem soils usually occur as non-saline varieties. Thin solonetzous varieties ($A_1 < A_{ar}$) occur on ridge slopes, whereas slightly saline varieties occur at the bottom of ridge slopes as patches in microdepressions. The lower portions of troughs and especially, of kettle-holes are occupied by meadow-chernozem strongly solonchakous soils and by solonchaks varying in solonetzisation. The central portions of troughs

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and kettle-holes, where much water accumulates in spring, are occupied by chernozem-meadow and meadow-boggy soils with clear signs of gleyisation.

The area of the paleoalluvial plain under saline soils tends to increase from top to bottom, i.e. soda salinity grows upwards while sulphate and chloride salinity downwards (Zolnikov, 1954). The geomorphology of the Central-Yakutian alluvial plains and the topography of its salinity and its water-salt regime enables the following conclusions to be drawn as to the genesis of salts in the local soil and subsoil.

As the surface of the plain gradually lost its alluvial regime, it went dry and stored up salts due to the evaporation of surface and ground waters. During the cold period at the end of Pleistocene, the surface was affected with young permafrost, the salts being transported upwards to the freezing screen by the capillary moisture ascending from the subsoil water and subsoil proper. The salt reserves in the upper alluvium and in the upper soil were as a result increased.

With the permafrost setting in at a very uneven pace, backwater was formed and the ground water opened into the surface giving rise to icings similar to modern ones wherever the permafrost was thin enough. The icings appeared in winter and disappeared in summer for a very long time thus causing the salts to accumulate in the upper soil layer. These phenomena were largely confined to the flat primary portions of the paleoalluvial plain with a shallow ground-water table, and especially to the intersections of heterochronous levels of that plain. The proof of this is the wide occurrence of strongly saline soils and lakes at such portions (Zolnikov, et al., 1962). The modern river valleys were formed against the background of multiannual permafrost whose deep strata (200—500 m) cut off ground waters from soils. The contact of soils with ground waters is now maintained only under the beds of deep lakes and rivers. Under the circumstances, the river water as such made the only source of salts. According to our findings, there must have been a number of succesive stages of salt accumulation in the modern valleys of such rivers as Lena or Vilyuy (Elovskaya, and Konorovsky, 1964).

During the lower alluvial phase, the accumulation of calcium and magnesium carbonates in loamy interlayers went on. Most soluble salts forming due to the evaporation of river water in kettle-holes, were washed and removed through a lateral intrasoil discharge following the spring decrease in water level. In spring, the whole of the middle alluvial plain and the lower parts of the high alluvial plain remain under water and in some years the whole of the high alluvial plain does. After spring flood, the local soils remained moist in excess of the minimum water-absorption capacity and to a depth of almost the whole seasonally thawing layer. Gradually yielding moisture for evaporation and transpiration, the soils stored up salts in their upper layer.

The multiannual freezing prevented the outflow of these salts during subsequent floods. As a result, the salt content of the flood soils did not grow much in size, especially at the bottom of lower portions of slopes in and around mesodepressions. The process recurring for hundreds of years, the soils have been strongly salinised even at the high alluvial plain, and especially

in mesodepressions. Thus, at the elevated sites of the high alluvial plain, the dry salt residue in the upper-water layer varies from 0.28 to 0.46%, whereas in the mesodepression it is as high as 1.2% with salts concentrating in the upper 30—40 cm layer.

Salts accumulated most intensively during the deposition of loamy alluvium, especially at the sites where river water had a poor discharge. On sandy soils also at sites where the water runs off well, there was little or no salt accumulation. Salt accumulation in soil is virtually zero during the phase of supra-alluvial terraces, since the latter have no contact with river water, with the exception of those sites at which ground waters or salt-bearing rocks outcrop.

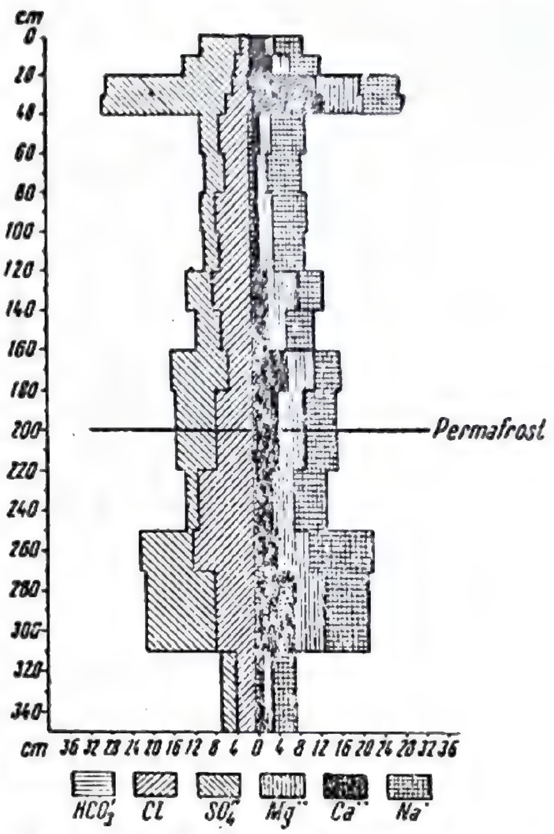

Fig. 1. Salt Profile of Meadow-Chernozem Solonetzous Medium-Solonchakous Soil. (point 4);

At such places, the salts accumulated during the previous phase are only subject to redistribution by surface (atmospheric), and occasionally, by supra-permafrost waters. These salts may be partly diverted into water bodies with changes in the hydrographic network. The salts are differentiated over the relief according to solubility giving rise to soils of soda, sulphate, and chloride salinity. The salts of the seasonally-thawing layer are syngenetic with their enclosing alluvium, which is evident from the high content of chlorides and sulphates, such as gypsum, in the permafrost ground strata occuring below the limit of maximum thawing (fig. 1).

The most common type of salinity in the soils of the Lena valley is chloride-sulphate, while the most widespread solonetzes are high- and medium-columnar. The composition of these soils is presented in table 1 and figure 2.

The stationary study of the salt and water regimes of saline soils in the Lena River valley near Yakutsk shows that the presence of permafrost and the absence of ground waters make the dynamics of salts appear very different as compared with the soils of other regions. The migration of salts in the profile as well as the fluctuations in the concentration of soil solutions are anything but intensive. Any appreciable migration of salts is confined to the upper seasonally-thawing layer.

The content of salts in the upper profile changes no more than twofold and for chlorine no more than threefold in both directions, whereas in other regions of the country in the presence of ground waters, the variation in salt concentration may be 10 times as high or as low (Kovda, 1947).

According to 3—4 year observations, the total chlorine and salts throughout the annually-thawing layer remain constant (fig. 3) for the meadow-chernozem saline soils of the Lena valley. This should indicate either the absence

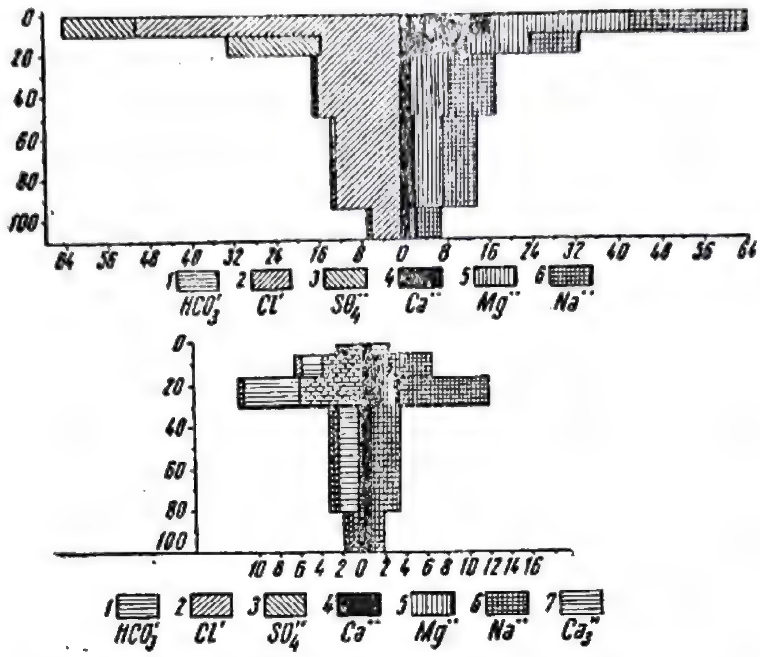

Fig. 2. 1. Salt Profile of Sulphate-Chloride Solonchak; 2. Salt Profile of High-Columnar Solonetz.

of a lateral water-salt discharge or, which is less likely, the equilibrium of salt inflow and outflow. A lateral discharge would be possible in the presence of ground or supra-permafrost waters or if the soil moisture content exceeded the maximum field capacity. However, the meadow-chernozem soils under study have neither ground nor supra-permafrost waters and it is only in pla-

Table 1

Water-extract data for sulphate-chloride solonchak and high columnar solonetz, %%

Depth cm	Dry residue	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	pH	CO_3^{--}
119									
0—10	5.12	0.06	1.76	0.68	0.33	0.32	0.50	8.0	
10—19	2.59	0.04	0.56	0.80	0.24	0.14	0.22	8.0	
23—33	1.10	0.05	0.56	0.02	0.05	0.07	0.19	8.5	
50—62	1.14	0.05	0.49	0.03	0.04	0.06	0.20	8.1	
95—109	0.53	0.04	0.22	0.02	0.02	0.01	0.12	8.6	
111									
0—5	0.23	0.09	0.01	0.04	0.01	trace	0.05	8.9	none
6—16	1.56	0.35	0.02	trace	0.04	trace	0.10	10.1	0.11
16—30	1.89	0.69	0.01	0.02	0.03	0.02	0.18	10.1	0.18
40—60	0.31	0.15	0.01	0.03	0.01	trace	0.07	9.9	0.02
80—100	0.17	0.07	0.01	0.02	0.01	trace	0.02	9.2	0.01

ces that the supra-permafrost soil horizons have a moisture supply in excess of the maximum field capacity. The migration of salts during the annual cycle may be described as follows (Elovskaya, 1964). In the freezing

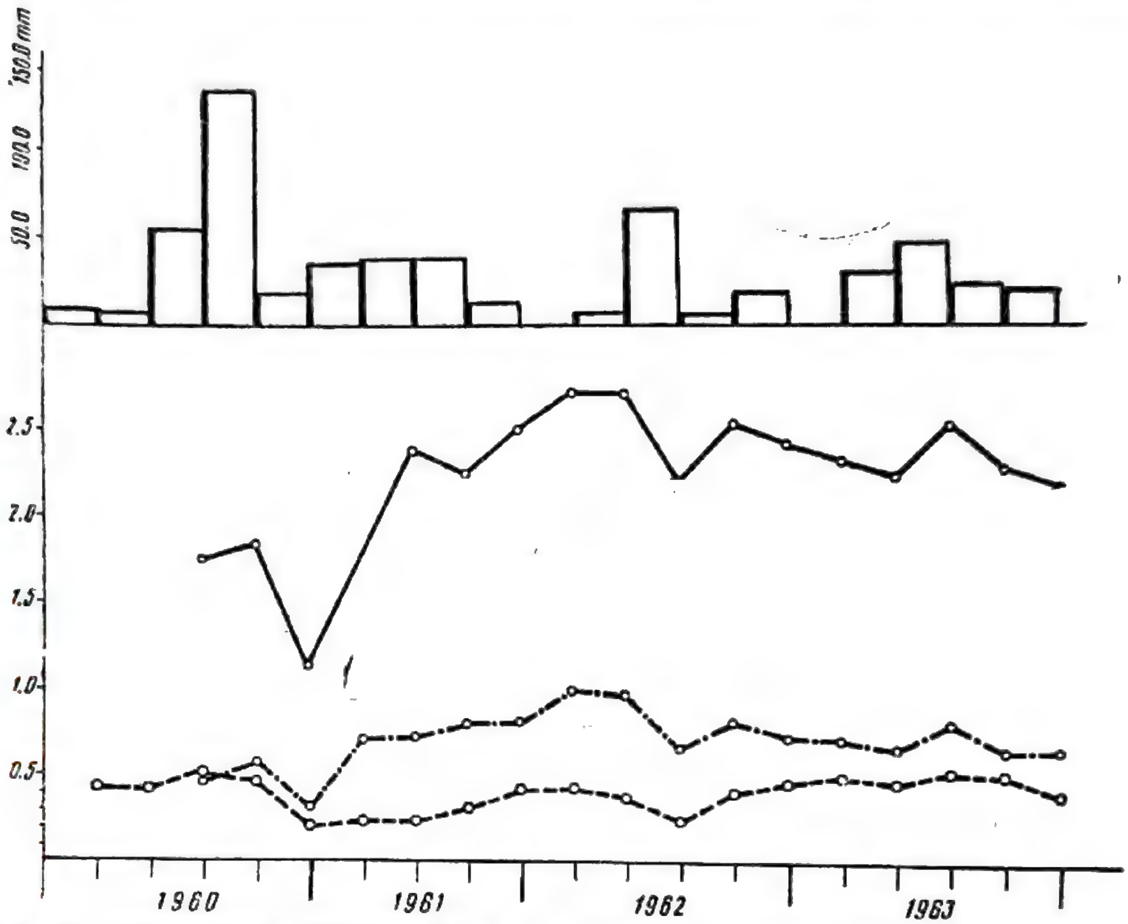

Fig. 3. Dinamics of Chlorine Stock in Meadow-Chernosem Medium-Saline Soil for 1960 — 1963 (kg/m²)
(The Chlorine content was determined annually from May to September) in the upper part Precipitations, mm; lower curve—Chlorine Stock in 0—40 cm layer, middle curve—40—80 cm, upper curve—0—120 cm.

period, the salts ascend from the lower to the upper horizons of the seasonally-thawing strata being transported in time of freezing by the film-capillary moisture. The upward flow of moisture to the freezing surface is explained by the temperature gradient. Since the soil is frozen downwards faster than upwards (by the time the upper and lower freezing fronts meet, some 160—180 cm are frozen down to the contact and only 30—40 cm up to the contact), the migration of salts should essentially proceed up the profile. Thus, the salinity of the upper horizons goes up by 20—30%. According to our investigations, in order to obtain such increase the migration of 20 mm of water should suffice for strongly-saline soils and of 10 mm of water for medium-saline soils. It was also shown that the total increase in moisture in winter is about 30 mm in the 0—50 cm soil layer.

In spring, the soil is moistened by melt water to a depth of 30—40 cm. As thawing proceeds, most of the salts are transported downwards due to the thermogradient, while their smaller portion ascends to the drying front due to the moisture gradient.

The dynamics of salts in the upper horizons in summer depends on the total amount of precipitations. In dry years, which are by no means rare, these horizons are the place of salts accumulation, which was observed in 1961—1962 when only 38 mm and 6 mm of precipitations fell in the second half of the summer, respectively.

With relatively abundant precipitations, e. g. in the second half of the summer of 1960 (133 mm), the bulk of profile gets desalinised. However, precipitations usually redistribute salts only in the upper 40—50 cm, whereas their influence on the deeper horizons is an exception rather than a rule. The observed migration of salts in the lower horizons in summer probably depends on the influence on the film-capillary moisture by the thermogradient.

It was revealed that the concentration of soil solutions in meadow-chernozem saline soils changed appreciably only in the upper 20 cm. Early in summer it usually drops increasing nearly twice towards autumn. In places, the total concentration of soil solution reaches towards autumn 25—33 g/l being toxic to certain plants.

With decreasing temperature, the solution gets slightly alkaline, some of the univalent cations becoming exchangeable and thus less active, i.e. a peculiar sort of solonetzisation takes place.

The special nature of the water and salt regimes of cryogenic meadow-chernozem saline soils makes one reconsider their possible reclamation by leaching and irrigation. It is therefore essential to fix the amounts and timing for saturating the soil with moisture for purposes of leaching and promoting vegetation. This is urgent in order to immobilise the salt reserves in the upper permafrost and thus to prevent secondary salinisation.

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SUMMARY

Saline soils are common in Central Yakutia. The most widespread are cryogenic meadow-chernozem saline soils. They have a badly frost-cracked surface, rather shallow multiannually frozen parent material, and a thin humus horizon ranging from 10 to 30 cm. The humus horizon contains 6—12% of humus, 0.2—0.5% of nitrogen, and 0.13—0.23% of phosphorus. Its absorption capacity ranges from 15 to 35 me/100 g of soil, and the pH of its water extract is 6.7—7.5. Among the investigated soils, sulphate-chloride type of salinity prevails. High-and medium-columnar solonetzes with soda salinity prevails among the solonetzes.

Cryogenic saline soils of Yakutia have a number of peculiarities in the dynamics of salts and their genesis because of the presence of a thick mass of permafrost and extra-continental climate. The migration of salts in soil profile and the range of fluctuations in the concentration of soil solutions are not intensive.

RÉSUMÉ

Les sols salins sont communs dans la Yakoutie Centrale. Les plus répandus sont les sols salins de chernozem - prairie cryogéniques. Ils présentent une surface fortement crevassée par le gel, un matériel parental peu profond gelé pendant des années, et un horizon mince d'humus d'une épaisseur de 10 à 30 cm. L'horizon d'humus a une teneur en humus de 6—12%, en azote de 0,2—0,5% et en phosphore de 0,13—0,23%. Sa capacité d'absorption est comprise entre 15 et 35 me/100 g de sol et le pH de son extrait aqueux est de 6,7—7,5. Parmi les sols étudiés prévaut le type de salinité sulfato-chlorurée. Parmi les solonetz prévalent ceux à structure colonnaire forte et moyenne à salinité sodique. Les sols salins cryogéniques de Yakoutie présentent un nombre de particularités dans la dynamique des sols et de leur genèse à cause de la présence d'une masse épaisse de sols gelés en permanence et du climat continental excessif.

La migration des sels dans le profil de sol n'est pas intense et la gamme des fluctuations dans la concentration des solutions de sol n'est pas large.

ZUSAMMENFASSUNG

Salzböden sind in Zentral-Yakutien allgemein verbreitet. Die weitaus verbreitetsten sind die kryogenen salzigen Wiesentschernoseme. Sie weisen eine stark durch Frost rissige Oberfläche, ein eher seichtes, viele Jahre hindurch eingefrorenes Ausgangsmaterial und einen dünnen Humushorizont auf, der zwischen 10 und 30 cm schwankt: der Humusgehalt dieses Horizonts beträgt 6—12%, der Stickstoffgehalt 0,2—0,5% und Phosphor 0,13—0,23%. Seine Absorptionskapazität liegt zwischen 15 bis 35 me/100 g Boden, das pH seines Wasserextraktes beläuft sich auf 6,7—7,5. Bei den untersuchten Böden herrscht der Sulfat-Chlorid Typus von Salzigkeit vor. Unter den Solonetzen herrschen jene von stark- und mittelsäulenförmiger Struktur mit Soda-Salzhaltigkeit vor.

Die kryogenen Salzböden von Yakutien weisen eine Anzahl von Eigenheiten in ihrer Salzdynamik und deren Genese auf, die auf das Vorhandensein einer mächtigen Dauerfrostbodenmasse und des kontinentalen Klimas zurückzuführen sind.

Die Salzwanderung im Bodenprofil und die Schwankungsspanne in der Bodenlösung-Konzentration sind nicht bedeutend.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964
VI. 20

LE PROCESSUS DE SALINISATION SECONDAIRE DU SOL DANS LES PARCELLES DE RIZIÈRE DISPOSÉES EN BANQUETTES

A. MĂIANU [1]

C'est un fait bien connu que, par l'irrigation des terrains qui présentent des conditions de salinisation potentielle, on constate une redistribution des sels du sol et de l'eau phréatique des secteurs plus éléves des systèmes d'irrigation vers les secteurs plus bas, qui, faute d'un drainage efficace, subissent le processus de salinisation secondaire (Darab, 1956; Haywards, 1957; Kovda, 1947; Rozanov, 1956). Cette constatation correspond à la loi naturelle générale, selon laquelle les sels s'accumulent à la surface de la terre dans les zones de dépression d'un terrain ou d'une unité physico-géographique quelconque (Kovda, 1947, 1961). En étudiant les processus de salinisation secondaire des sols irrigués de la Lunca du Danube (plaine inondable du Danube), on a signalé un cas particulier concernant l'influence du relief sur la salinisation secondaire des sols de rizière. Ce processus est plus accusé et plus rapide dans les secteurs élevés et à pente plus accentuée des rizières, avant d'apparaître visiblement dans les secteurs plus bas, et plans. Les recherches effectuées ont démontré que l'accélération du processus de la salinisation secondaire du sol de ces secteurs est due à la disposition des parcelles de rizières en banquettes (Măianu, 1962). La présente étude a comme but d'expliquer le mécanisme de la salinisation secondaire du sol dans le cas mentionné, de mettre en évidence les facteurs qui y interviennent et de présenter d'une façon succinte les résultats obtenus concernant les méthodes de prévenir et de combattre ce processus.

La pente initiale des terrains aménagés à présent comme rizières dans la plaine inondable du Danube, était comprise entre 0,1 et 8‰. Pour éviter les grands déplacements de terre nécessaires au nivellement des parcelles, les superficies, ayant des pentes plus raides que 8‰, n'ont pas été aménagées. Dans ces conditions, les différences de niveau qui ont été réalisées entre les diverses parcelles se situent entre 5 et 41 cm, pour les parcelles ayant une largeur de minimum 50 mètres.

Dans la pratique courante, l'irrigation d'un secteur de rizière, tel que celui présenté dans la figure 1, commence par la submersion des deux premi-

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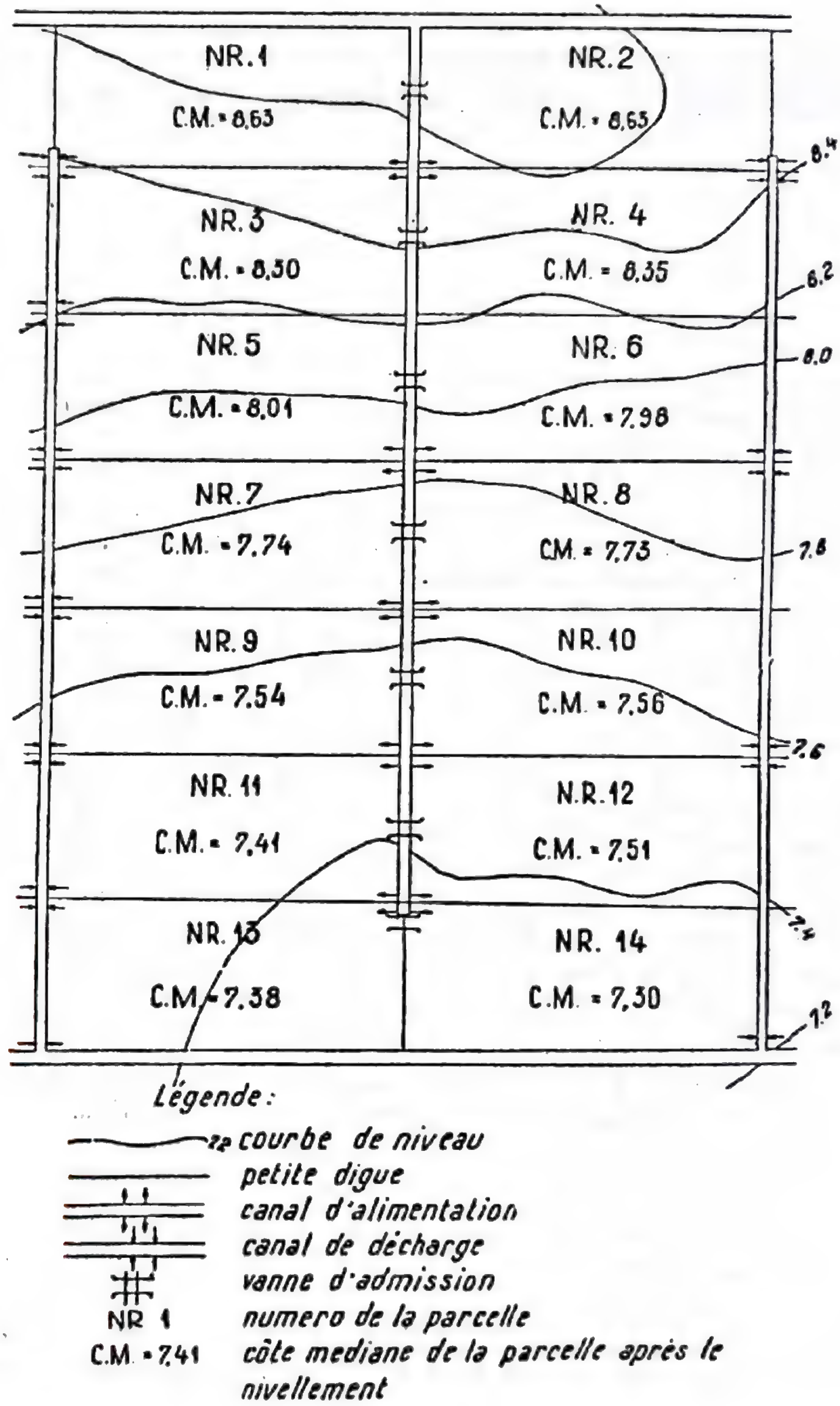
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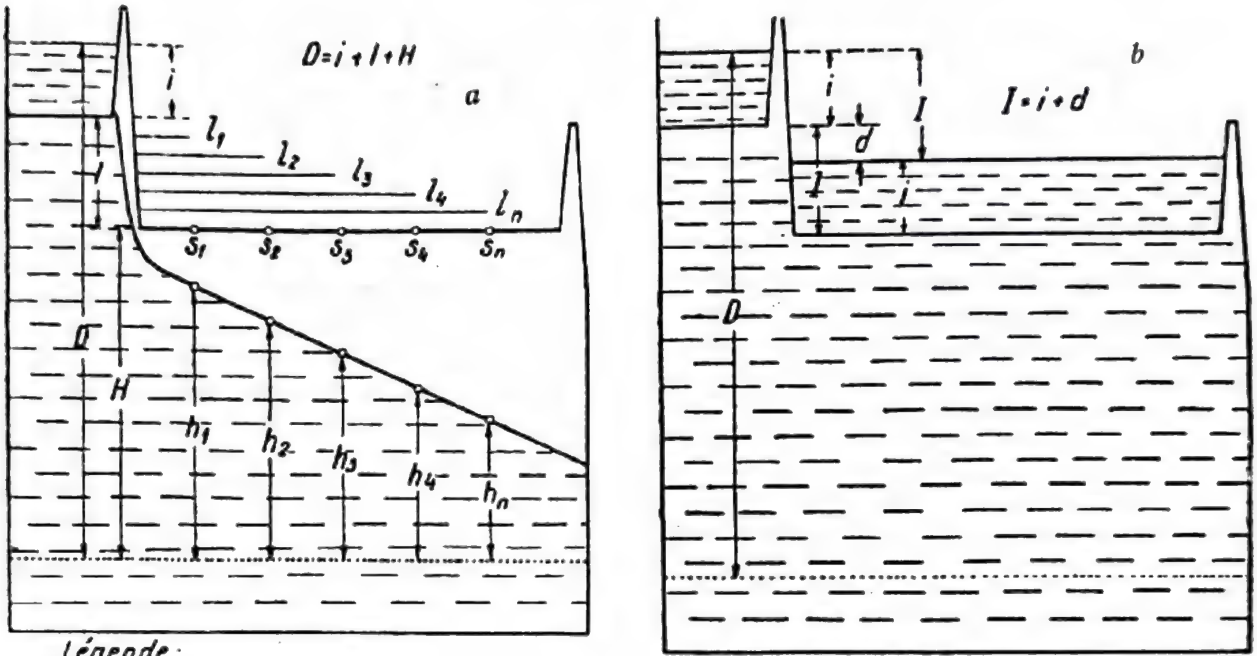
NR. 8
C.M. = 7,73
7,8
NR. 9
C.M. = 7,54
NR. 10
C.M. = 7,56
7,6
NR. 11
C.M. = 7,41
N.R. 12
C.M. = 7,51
7,4
NR. 13
C.M. = 7,38
NR. 14
C.M. = 7,30
7,2
Légende :
7,2 courbe de niveau
petite digue
canal d'alimentation
canal de décharge
vanne d'admission
NR 1 numero de la parcelle
C.M. = 7,41 côte mediane de la parcelle après le nivellement

Fig. 1.

ères parcelles les plus hautes (nr. 1 et 2), adjacentes au canal principal d'alimentation, on continue par la submersion successive des parcelles suivantes, toujours deux à deux, en finissant par l'inondation des deux dernières parcelles (nr. 13 et 14), adjacentes au canal principal de décharge. Par rapport au débit d'eau dans le canal d'alimentation, la submersion du sol au printemps et l'ensemencement du riz dans un secteur comme celui de la figure 1 peuvent être réalisés en 2—3 jours. Dans ces conditions, la salinisation secondaire du sol se poursuit par deux mécanismes distincts. Le premier mécanisme a lieu dans l'intervalle compris entre l'introduction de l'eau sur les parcelles, au printemps, jusqu'à l'évacuation avant la récolte du riz. Dans cette période, le facteur actif de la salinisation secondaire c'est l'élévation du niveau de l'eau phréatique minéralisées des parcelles plus basses, sous l'action de la pression hydrostatique de l'eau de submersion des parcelles voisines, plus hautes et sans que l'évaporation intervienne. Le deuxième mécanisme opère pendant la période quand le sol n'est pas submergé. Dans ce cas, le facteur actif de la salinisation este l'évapotranspiration des eaux phréatiques minéralisées, peu profondes.



Légende:
Niveau de l'eau phréatique avant (........) et après (o—o—) l'irrigation de la parcelle en amont.

première etape

Légende
.... niveau de l'eau phréatique avant l'irrigation de la parcelle en amont.

deuxième étape

Fig. 2.

La salinisation secondaire du sol dans des parcelles de rizières disposées en banquettes a lieu quant au premier mécanisme, en deux étapes et par le deuxième mécanisme, dans une troisième étape.

La première étape de salinisation secondaire du sol correspond à la période d'inondation des parcelles de rizière, au printemps (2—3 jours environ).

Au cours de l'introduction de l'eau d'irrigation sur la parcelle en amont, afin d'obtenir le niveau d'eau nécessaire à la submersion (i), on réalise la saturation totale en eau du sol jusqu'au niveau de l'eau phréatique en établissant ainsi la continuité entre l'eau d'irrigation et l'eau phréatique. La pression hydrostatique exercée sur la nappe phréatique est en fonction de la différence de niveau (D) entre le plan de l'eau de submersion en amont et le niveau de l'eau phréatique :

$$D = i + I + H, \tag{1}$$

où :

i est la profondeur de la couche de l'eau de submersion,
I — la hauteur de dénivellement entre les deux parcelles,
H — la profondeur initiale, de l'eau phréatique dans la parcelle en aval.

L'élévation du niveau de l'eau phréatique dans la parcelle en aval est le résultat de la pression hydrostatique. Au moment de la stabilisation de la pression hydrostatique de l'eau de submersion et de celle de la pente d'écoulement de l'eau phréatique, la profondeur de l'eau phréatique est égale à celle mesurée dans les sondages $S_1, \ldots, S_n$.

Le degré de la salinisation secondaire du sol à travers les parcelles est ainsi plus élevé à mesure qu'on s'approche de la banquette entre les parcelles, le niveau de l'eau phréatique minéralisée augmentant lui aussi dans cette direction.

L'accroissement du degré de la salinisation secondaire du sol au cours de la première étape (GS_1) est une fonction de 8 facteurs :

L'accroissement du degré de la salinisation secondaire du sol au cours de la première étape (GS_1) est une fonction de 8 facteurs :

$$GS_1 = f\left(z, I, i, h, k, m, \frac{1}{H}, \frac{1}{l}\right), \tag{2}$$

où

z est un coefficient dépendant de la durée de l'étape de la salinisation,
I — la hauteur de la banquette entre les parcelles,
i — la profondeur de l'eau de submersion,
h — la hauteur de l'ascension du niveau de l'eau phréatique,
k — le coefficient de filtration du sol,
m — le degré de minéralisation de l'eau phréatique,
H — la profondeur de l'eau phréatique au printemps, avant l'introduction de l'eau dans la rizière,
l — la distance de la banquette entre les parcelles.

La deuxième étape de la salinisation secondaire de sol correspond à la période où toutes les parcelles de la rizière sont submergées. Dans cette étape, l'intensité du processus de salinisation est fort diminuée, puisque la pression hydrostatique — elle aussi—est plus réduite par rapport à la première étape.

Elle ne dépend désormais que de la hauteur de la banquette entre les parcelles (I), parce que:

$$I = i + \mathrm{d} + i + (I - i), \tag{3}$$

comme il résulte de la figure 2—*b*.

L'accroissement du degré de la salinisation du sol en cette deuxième étape (GS_2) est une fonction de 6 facteurs, à savoir:

$$GS_2 = f\left(z,\ I,\ i,\ k,\ m,\ \frac{1}{l}\right), \tag{4}$$

dans laquelle les indices ont les significations plus haut mentionnées.

La troisième étape de salinisation secondaire du sol a lieu après l'évacuation définitive de l'eau, en automne. Dans cette étape, le facteur actif de la salinisation est l'évapotranspiration des eaux phréatiques minéralisées, qui maintiennent encore longtemps un niveau assez élevé.

L'accroissement de degré de la salinisation du sol au cours de cette étape (GS_3) est une fonction de 4 facteurs:

$$GS_3 - f\left(z,\ m,\ e,\ \frac{1}{H'}\right), \tag{5}$$

t et m sont les significations plus haut mentionnées,
e — l'intensité de l'évapotranspiration, dans les période automne-printemps,
H' — la profondeur de l'eau phréatique.

Par le fait qu'au cours de la période automne-printemps l'évapotranspiration a une intensité réduite, l'indice GS_3 a des valeurs basses. Il faut mentionner que la majorité des facteurs dont dépendent la valeurs GS_1, GS_2 et GS_3 sont, en général, facilement déterminables par de simples mesurages.

Par conséquent nous considérons comme possible de les calculer à la suite d'une eventuelle réduction du nombre de quelques-uns des facteurs cités (en réunissant les uns et en négligeant les autres) et en établissant les fonctions par lesquelles ils interviennent dans les formules. C'est le coefficient de la filtration du sol (k) et surtout l'intensité de l'évapotranspiration dans la période automne-printemps (e) qui peuvent être déterminés plus difficilement.

Dans la practique, cependant, la somme multianuelle des valeurs GS_1, GS_2 et GS_3, représentant le degré de salinisation secondaire du sol à un certain moment (y), présente la plus grande importance. A la suite des recherches effectuées on a constaté qu'entre cette valeur synthétique (y) et la hauteur de la banquette (x) il existe une corrélation empirique étroite, qui exprime, en effet, la synthèse de l'action de tous les facteurs mentionnés plus haut. Ainsi, dans les rizières de la plaine inondable du Danube, sur des parcelles d'une largeur de 50 m, emplacées sur des sols à texture moyenne, ayant des eaux phréatiques contenant 50—20 g/l sels, on a constaté, 4—5 ans après le commencement de l'irrigation, les corrélations de la figure 3. Ces corrélations démontrent que la salinisation secondaire du sol par ce processus

peut être signifiante sur des parcelles de rizière qui sont divisées par des banquettes plus hautes de 10 cm.

Les mesures qui s'imposent pour prévenir et combattre la salinisation secondaire des sols de rizière par suite de ce mécanisme sont les suivantes : emplacer les rizières seulement sur des terrains ayant une pente plus faible

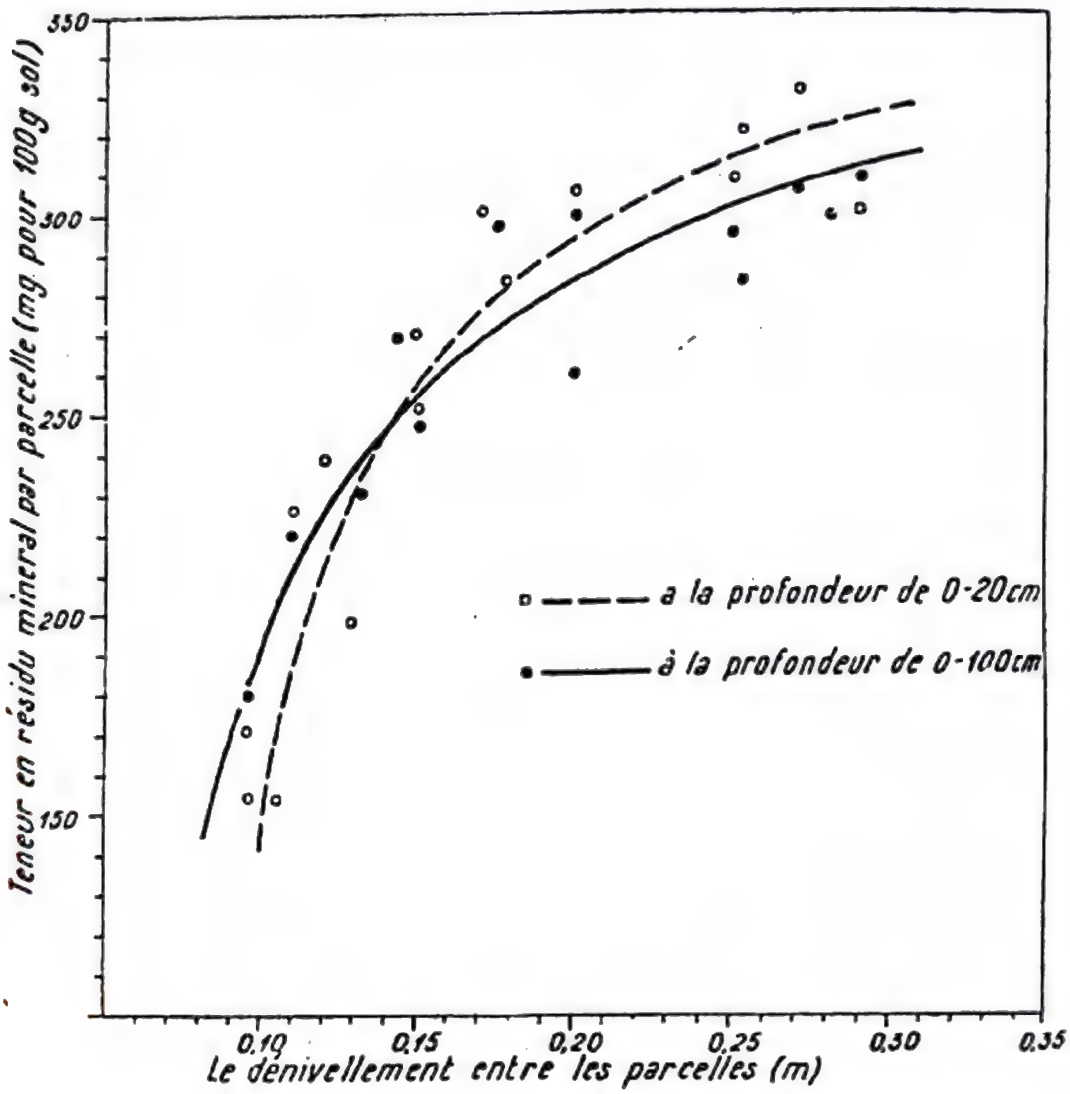


Fig. 3.

de $3^0/_{00}$, quand celles-ci présentent des conditions de salinisation potentielle ; choisir la largeur des parcelles de telle façon que la hauteur des banquettes entre les parcelles ne dépasse pas 10 cm ; isoler les parcelles en creusant des canaux de drainage ou en emplaçant des écrans d'argile, avec une profondeur de plus de 0,75 m, sous la banquette de dénivellement entre parcelles. La prévention partielle de la salinisation du sol par ce mécanisme peut être réalisée de même par l'irrigation des secteurs de rizière à partir des parcelles en aval vers celles en amont.

Quant à l'amélioration des sols, déjà salinisés secondairement par ce processus, il faut souligner l'importance des canaux de drainage ouverts, creusés sous les banquettes de dénivellement entre les parcelles. Ceux-ci sont très efficaces quand la hauteur des banquettes est inférieure à 30—40 cm. Dans ces conditions, certains sols, qui ont une texture moyenne et un grand degré de salinisation, ont été pratiquement entièrement dessalés au cours de seulement deux années, les productions de riz augmentant de 680—988 kg/ha à 2 016—2 094 kg/ha. Dans la 3ᵉ et 4ᵉ année on a obtenu sur ces sols des productions variant entre 4 500 et 6 200 kg/ha. Pour l'amélioration radicale du sol, en vue de la culture aussi d'autres plantes agricoles, qui ne sont pas irriguées par submersion continuelle, il est nécessaire d'assurer un drainage plus efficace.

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RÉSUMÉ

Sur des terrains en pente dépassant 3‰, sur lesquels les parcelles de rizière sont disposées en banquette, une accélération du processus de salinisation secondaire du sol peut avoir lieu sous l'influence de la pression hydrostatique de l'eau de submersion des parcelles en amont. Celles-ci déterminent une élévation importante du niveau de l'eau phréatique minéralisée, sous la parcelle voisine plus basse.

On peut prévenir et combattre ce processus en séparant les parcelles par des écrans d'argile ou des canaux de drainage, d'une profondeur supérieure à 0,75 m, dans les conditions d'un drainage général efficace, ainsi que par d'autres méthodes.

SUMMARY

On soil declivities exceeding 3‰, on which rice plots are arranged in terraces, an acceleration of the secondary soil salinisation process may occur, due to the hydrostatic pressure exerted by the flooding water of the higher plots. These produce a significant rise of the mineralized groundwater, under the lower neighbouring plot.

One may prevent and control this process, separating the plots by clay screens or open drainage ditches of a depth superior to 0.75 m, in efficient general conditions or by other practices.

ZUSAMMENFASSUNG

Auf Hanggeländen mit einer $3^0/_{00}$ übersteigenden Neigung, auf welchen Reisfeldparzellen auf Stufenterrassen angelegt sind, kann eine Beschleunigung des sekundären Versalzungsprozesses unter dem Einfluss des hydrostatischen Druckes des Überschwemmungswassers der oberhalb gelegenen Parzellen stattfinden. Diese verursachen ein erhebliches Steigen des mineralisierten Grundwasserspiegels der niedrigeren Nachbarparzelle.

Dieser Prozess kann dadurch verhütet und bekämpft werden, dass die Parzellen durch Tonscheidewände oder, im Rahmen einer allgemein wirksamen Dränung, durch Drängräben von einer 0,75 m übersteigenden Tiefe getrennt werden sowie durch andere Methoden.

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VI. 21

RATES OF SOIL SALINIZATION FROM SALTY GROUND WATER

BAHATTIN ÖZTAN, ST. H. KRASHEVSKI [1]

INTRODUCTION

The salinity and alkalinity problem areas encountered in Turkey are of such a magnitude that they require the intensive attention of Turkish soil scientists. A rough estimation indicates that there are about four million hectares of land that are suitable for irrigation. But, a sizable area of this land, about 3 million hectares, should be reclaimed before it could be put into intensive irrigated agriculture.

The main causes of salinity in Turkish soils derive from weathering of geological materials and from highly salt charged shallow ground water tables. The soils to be reclaimed will normally require drainage. A well constructed drainage performs two functions, i.e.: 1) lowering or controlling the ground water level and, 2) controlling the salinity.

Most of the known formulas for drainage design are based on data obtained from evaluation of certain physical properties of soils. The authors in their considerable work on reclamation of salt-affected soils in Turkey found that the common formulas for drainage design will produce a more than adequate drainage in saline or alkali soil. This is essential because of the unfavourable physical conditions of these soils.

The experience of the authors, gathered during investigations of requirements of soil reclamation, in the Ankara province, shows the discrepancies between the formula-calculated and the actual drainage needs determined by experimentation.

We use for example, the drainage equation of Hooghoudt (Luthin, 1957) and Kirkham, 1961. The calculated average spacing for drains is between 10—15 meters. However, the field experiments showed that the area could be drained and reclaimed adequately by constructing drains having 50 meters spacing when the desired depth in both cases was 150 centimeters. Interesting to note is that the experimental area consisted of clay soils having very slow permeability (NF—0.03 cm/hr), salinity of 2—14 mmhos/cm and high alkalinity (42—97% of Exch. Na).

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The above difference in drainage needs results from the presence and content of unfavourable chemical properties of soils. The chemical properties should be a factor or set of factors to be included in the drainage formula.

PROBLEMS INVOLVED

Presently there are no adequate criteria to evaluate and then reclaim soils and the salt charged ground waters. Kovda (1958) suggested an approach which is perhaps closest to the needs. The author showed that when a ground water table contains chlorides and/or sulfates, the critical point of groundwater suitability for irrigation is from 2 to 3 gr salt per liter. If carbonates are present, then their upper limit should be from 0.7 to 1.0 grams per liter. When the ions are higher than the limits above mentioned then sodium will render the soil unusable for most agricultural planting. If the salt contents are high, then the ground water table should be maintained at least at 200 to 250 cm depth. Kovda proposed the following formula to determine the critical depth to groundwater table:

$$Y = 170 + 8T^{\circ} \pm 15,$$

in which

Y — critical depth to water table in cm,
T — average annual temperature in centigrades,
8; 15 and 170 are proportionality factors.

This empirical formula has inherent inadequacy. Factors such as daily and seasonal variations in temperature affect inversely the capillary rise which in turn affects the distance to the water table. Also, according to the principles of physical chemistry, the force of the capillary rise, which is an important factor in the depth to soil water table, will be affected inversely by surface tension. Furthermore, high temperature will result in a high evaporation rate which will reduce the capillary rise. Thus, Kovda's formula is not quite satisfactory for calculating the depth of drainage; may be some modifications are necessary to Kovda's formula.

METHODS OF STUDY

1. *Aims of this investigation*

This investigation was conducted to:

— determine the quantity of capillary rise of ground water for different soils.

— determine the amount of salt which moves with water and is deposited in the soil.

— find the possibility of utilizing the two quantities shown above to design a drainage-spacing and depth.

2. *The equation used*

The water balance method was selected for the investigation of capillary rise and salt accumulation in the profile. In this method, when the water is in equilibrium with the all forces acting upon it, the following condition exists:

$$C + R + M_1 = M_2 + E + D,$$

in which

C — capillary rise in mm,
R — rainfall in mm,
D — amount of drained-out water in mm,
E — daily evaporation in mm,
M_1 and M_2 — amount of moisture in millimeters in the soil before (M_1) and after (M_2) experimental work.

Since the experiment was conducted under idealized conditions in the greenhouse, R and D factors were eliminated.

To arrive at the C factor, two values (W_n and Z_n) were determined. The W_n factor identifies the content of water expressed in millimeters, found in a known depth of soil column which has one square centimeter of surface area.

The Z_n factor determines the amount of sodium chloride in grams per one square centimeter of a soil layer with a depth of N. The calculation of C factor from its components W_n and Z_n and the definitions of their limits are those recommended by Zuur in 1930 as reported by Verhoeven.

3. *Equipment*

For this study drums with a round bottom 56 cm in diameter were used. These were about 200 cm in height. The capacity of these lysimeters was approximately 400 liters. The drums were insulated with asphalt paint. An individually regulated drain was connected to the bottom of all lysimeters.

4. *Procedures*

Three different depths to the ground water table were selected i.e., 100, 125 and 150 cm. The levels of the ground water table were kept constant by specially constructed equalizing tanks. To facilitate water movement from the groundwater level into the soil, a layer of gravel was placed into the bottom of each lysimeter. About 25.3 liters of water were required to produce a saturated condition in the gravel zone.

The lysimeter tanks in the greenhouse were filled with an alluvial sandy loam soil, while in the field experiment a residual clay loam soil was used, table 1 presents the physical and chemical properties of these soils.

To determine the quantity of salt which will move with water by capillary action, from sodium chloride saline water was made to contain EC =

Table 1

Physical and Chemical properties of soils used in experiment

Soil used	Depth sample	Sat. per-centa-ge	EC_{25} 10^3	Soluble ions in saturation extract in me/l											F.C.	Wilting point	Density	Volume Weight
				pH	Ca^{++}	Mg^{++}	Na^+	K^+	Total	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Total				
Sandy		37.5	0.68	8.0	3.33	1.33	1.65	0.05	6.94	tr.	3.53	0.4	0.64	6.57	18.7	8.9	2.63	1.44
	0—20	50	0.67	7.3	6.22	0.60	0.29	0.38	7.49	—	6.31	0.85	0.19	7.35	25.5	13.8		
	20—40	50	0.49	7.3	4.18	0.71	0.31	0.24	5.44	—	4.82	0.75	0.10	5.67	24.0	15.6		
	40—60	52	0.45	7.4	3.54	0.84	0.31	0.16	4.85	—	3.85	0.65	0.14	4.64	23.0	12.7		
	60—80	48	0.41	7.6	3.11	0.55	0.60	0.13	4.39	—	3.32	0.60	0.11	4.23	21.0	11.0		1.50
clay	80—100	45	0.39	7.6	3.11	0.66	0.33	0.10	4.20	—	3.32	0.75	0.12	4.19	19.0	10.6		
	100—120	43	0.39	7.6	2.90	0.56	0.39	0.11	4.96	—	3.21	0.55	0.15	3.91	20.0	13.0		
	120—150	47	0.39	7.6	2.36	1.00	0.39	0.08	3.36	—	3.00	0.60	0.14	3.74	23.0	12.3		

= 9.5 mhos/cm one mmhos of electrical conductivity equals 5 gr. of sodium chloride in one liter of water in both cases.

Daily records were kept for water used, soil temperature, and air temperature. Also, periodically, the concentration and depth to groundwater table were recorded. These were kept constant.

The experiment was repeated twice. The duration of this experiment was 112 days.

At the end of the experiment, the soil of each lysimeter tank was analysed. The sampling sections were: 0—30; 30—55; 55—85; 85—115; 115—150 cm respectively. These soil samples were analysed to determine moisture content and the electrical conductivity of the saturation extract.

RESULTS AND DISCUSSION

Measuring from the surface of the soil to the groundwater table, the following values have been obtained for moisture content and electrical conductivity (table 2).

Table 2

Relation between distance to groundwater table, soil moisture and electrical conductivity

Soil layer from	Per cent moisture		EC_{25} 10^3 in sat. ext. mmhos/cm	
	greenhouse	field	greenhouse	field
0—30	4.22	16.33	0.67	0.57
30—55	7.44	12.04	0.88	0.43
55—85	13.24	15.00	2.26	0.39
85—115	17.72	16.77	3.32	1.08
115—150	24.45	23.00	4.90	4.07
Saturated zone	37.00	50.00	9.50	9.50

These data indicate that the farther the distance from ground water, the less accumulation of moisture and salt in the soil.

The important fact here is that according to the statistical analyses the regression lines for both soil moisture and electrical conductivity, as related to the depth of groundwater, show highly significant correlation, which would occur in uniformly textured soils. The regression lines are shown in figures 1 and 2.

The above data has been calculated for the evaluation of capillary rise.

a. *Capillary rise*

Capillary rise is an important factor in the movement of salts, contained in the groundwater (table 3). The original groundwater contained 4.797 g/l of NaCl (9.50 micromhos/cm) and the difference between the moisture content

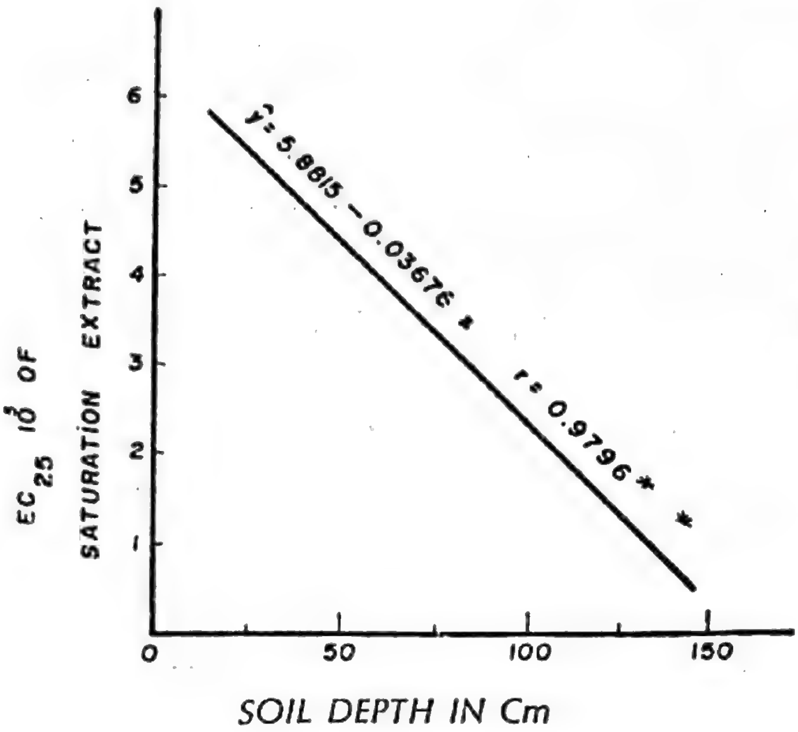

Fig. 1. Effect of Ground Water Depth on Salt Accumulation in Soil (ground water had EC of 9.5 $EC_{25}\ 10^3$).

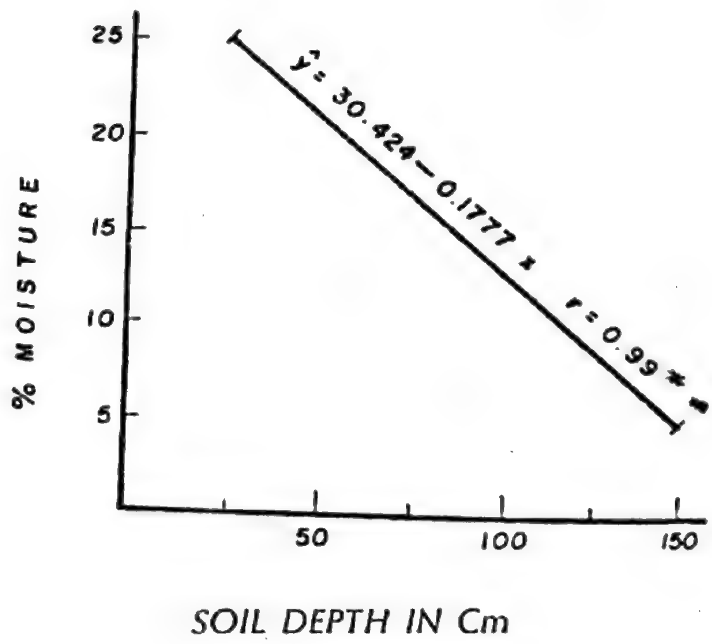

Fig. 2. Relation Between Soil Moisture Content and Depth to the Ground Water Table.

Table 3

Capillary rise and factors in greenhouse exp.

Depth of soil cm	Beginning of Experiment		End of Experiment	
	Wn_1/mm	Zn_1/g	Wn_2/mm	Zn_2/g
0—30	55.19	0.0040	18.1	0.004
30—55	51.10	0.0051	26.8	0.008
55—85	61.32	0.0051	57.2	0.021
85—115	61.32	0.0051	76.5	0.031
115—150	71.51	0.0060	121.5	0.049
Total	300.47	0.0253	300.1	0.113

in the soil at the beginning and the end of the greenhouse experiment was 0.46 mm/cm² in the 150 cm soil column. This was obtained by subtracting the value Wn_1 (300.47) from Wn_2 (300.1). The accumulated salt content was 0,0877 g/cm² in the same column (Zn_1 0.113—Zn_2 0.0253). The important question is: how many milliliters of water did move in the profile to carry this amount of salt. This question can be resolved by calculating as follows:

$$1{,}000 \times \frac{0.0877}{4.797} = 182.82 \text{ mm/cm}^2/150 \text{ cm depth.}$$

The difference between the moisture and salt content in the soil at the beginning and the end of the field experiment was:

$$Wn_1 = 268.7 \qquad Wn_1 - Wn_2 = 139 \text{ mm/cm}^2$$

$$Wn_2 = 406.9$$

$$Zn_1 = 0.0316 \qquad Zn_1 - Zn_2 = 0.0708 \text{ gr/cm}^2\text{/cm}$$

$$Zn_2 = 0.1029$$

$$\text{Capillary rise from the groundwater} = \frac{0.0708}{4.797} \times 10{,}000 = 147.59 \text{ mm/cm}^2.$$

b. *Evaporation*

The amount of water evaporated during the experimental time was 45.81 liters. Since the lysimeter tank surface was 2505.7 cm² and the amount of water risen per cm² was 182.85, then the quantity evaporated was:

$$\frac{2505.7 \times 182.85}{100\,000} = 45.81 \text{ liters.}$$

Some of the factors involved here should be elucidated.

The facts are:

1) the lysimeter contained in the gravel zone 25.3 liters of water;

2) at the beginning, the soil itself had 75.3 liters of moisture;
3) the capillary rise brought up 45.81 liters of water;
4) the lysimeter received 71,0 liters of additional water;
5) at the end of this experiment there was 75.20 liters of water.

The soil moisture difference was 0.10 liters (75.30—75.20) of water.

The total moisture or moisture due to capillary rise at the end of the experiment was 45.91 liters (45.81 + 0.10). The evaporation im mm/day in each cm² is:

$$\frac{45.91}{\text{days} \times \text{surface}} \quad \text{in this experiment:}$$

$$\frac{45.91 \times 10000}{112 \times 2505.07} = 1.635 \text{ mm/day.}$$

Under field condition the following values were obtained for evaporation:

rainfall = 143.7 mm

due to cap. rise = 153.3 mm

$$\text{evaporated in the day} = \frac{153.3}{112} = 1.37 \text{ mm/day}$$

The daily evaporation rates from the field (1.37) and the greenhouse (1.64) are quite similar.

c. *Salinization rate*

The salinization rates for the 112 day duration of these experiments are shown in table 4.

Table 4

Salinization Rate $EC_{25}10^3$/Day/Soil Layers in cm From Surface

	0—30	30—55	55—85	85—115	115—150
Greenhouse	—	0.002	0.014	0.023	0.038
Field	—	—	—	0.014	0.032

In making these calculations, the following assumptions have been made:
1) that the depth to the ground water table is constant;
2) „ „ concentration of salt in the ground water is constant;
3) „ „ salt movement in the soil is governed by water movement and that the diffusion rate is negligible.

These assumptions were checked during the experimental work and it was determined that they were valid, excepted for the diffusion rate. In the

greenhouse experiment, it has also been found that the capillary rise and salt accumulation from the salty ground water table are in a proportional ratio. Under the field experiment, the capillary rise and salt accumulation were proportional only in the 85 to 150 cm. of soil depth. Leaching by rainfall probably influenced the salt accumulation in the 0—85 cm depth. This means that the salt accumulation in the soil profile is due mainly to the concentration and the depth to the groundwater table but is influenced by rainfall or irrigation. The salt concentration and depth to ground water should therefore, be considered in reclamation of soils or in management of irrigated lands to prevent salt accumulation.

In the greenhouse experiment the daily rates of salt accumulation in the different soil zones appear to be high. However, the data were obtained in an optimal condition in the greenhouse. In the field the effects of variable moisture from precipitation, winds and their intensities, temperature changes, and other factors will influence the salt accumulation considerably, and the results were therefore different from those obtained in the greenhouse experiment.

Calculations from the experimental data shows (figure 3) that during an evaporation period of 10 months; when the ground water is at 150 cm

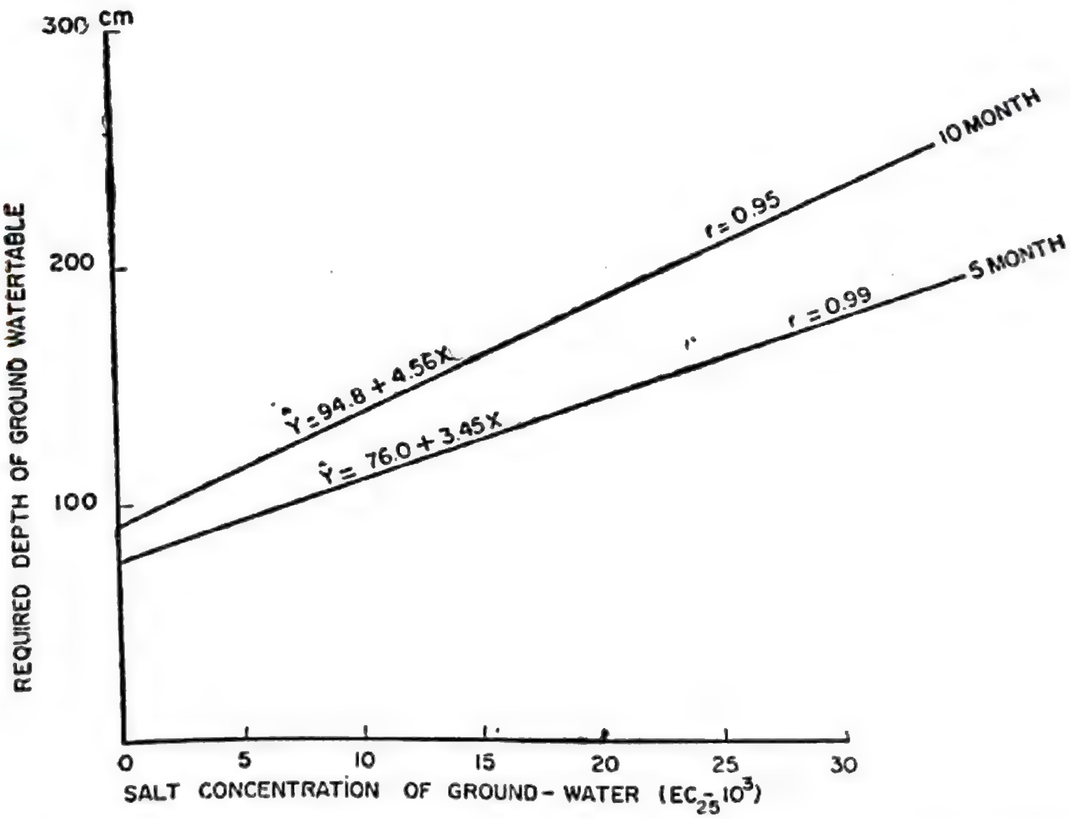

Fig. 3. Relation between Electrical Conductivity and Depth to Safe *Ground Water.
* This figure assumes the safe depth of usable soil in 50 cm; the safe depth is a function of depth to the ground water and its concentration.

depth and it contains 12.7 mmhos/cm of electrical conductivity, the capillary rise from the water will bring sufficiently large quantity of salt up to 95 cm depth below the surface which will prevent normal plant growth at this depth. If the ground water table rises, drainage should be constructed to prevent salinization of soil.

The data calculated from the experimental work and presented below, show the relation between usable depth of soil and the depth of drainage needed to a lower one or to maintain the groundwater at a safe distance from the plant root zone.

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SUMMARY

The capillary rise of water and salt accumulation values have been determined in a soil under optimal environmental conditions in a greenhouse study, utilizing lysimeters with equalizers to control the level of ground water; and in the field, under normal Turkish field conditions. The results show that the proximity of groundwater table and its salt content have a positive influence on the salinity of the soil and their control through proper drainage is very important.

This study shows that, for Turkish dryland conditions where salinity problems exist and the electrical conductivity of the ground water averages around 15 mmhos/cm, the safe depth to such a ground water is 135 cm for a 5 month capillary rise period and 165 cm for a 10 month period.

RÉSUMÉ

L'ascension capillaire de l'eau et les valeurs de l'accumulation du sel ont été déterminées sur un sol, dans des conditions ambiantes optima, par une étude de serre, en employant des lysimètres à égalisateurs, afin de contrôler le niveau de la nappe phréatique; et également au champ, dans des conditions de champ normales en Turquie.

Les résultats prouvent que la proximité du plan de la nappe phréatique et de sa téneur en sel ont une influence positive sur la salinité du sol et que leur contrôle, par un drainage convenable est très important. Cette étude montre que pour les conditions dans les régions sèches de la Turquie oú se posent des problèmes de la salinité et où la conductibilité électrique de la nappe phréatique est en moyenne d'environ 15 mm hos/cm, la profondeur sans risques jusqu'une telle nappe phréatique est de 135 cm pour une période de 5 mois d'ascension capillaire et de 165 cm pour une période de 10 mois.

ZUSAMMENFASSUNG

Kapillaraufsteigen von Wasser und Salzanhäufungswerte wurden an einem Boden unter optimalen Umweltfaktoren in einer Treibhausuntersuchung ermittelt, unter Benützung von Lysimetern mit Ausgleichern, um den Grundwasserstand zu prüfen; dasselbe auch im Feld unter normalen türkischen Feldverhältnissen. Die Ergebnisse beweisen, dass die Nähe des Grundwasserspiegels und sein Salzgehalt einen positiven Einfluss auf die Salzhaltigkeit des Bodens ausüben, und dass ihre Kontrolle durch geeignete Entwässerung sehr wichtig ist.

Diese Abhandlung zeigt, dass für türkische Trockenlandbedingungen, wo Salzhaltigkeitsprobleme bestehen und die elektrische Leitfähigkeit des Grundwassers durchschnittlich rund 15 mmhos/cm beträgt, die gefahrlose Tiefe zu solchem Grundwasser 135 cm für eine fünf Monate lange Kapillaraufsteigensperiode und 165 cm für eine Periode von zehn Monaten beträgt.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

DRAINAGE REQUIREMENTS OF IRRIGATED SOILS IN RELATION TO SALINITY

W. H. VAN DER MOLEN, J. H. BOUMANS [1]

1. INTRODUCTION

In irrigated fields, salinity may already develop if the only source of salts is the irrigation water. Even with waters of excellent quality a few thousand kilograms of soluble salts are added per hectare and per year, and with poor quality waters this amount may easily be ten times higher.

Therefore, in the long run a strong salinization will occur, if these salts are allowed to accumulate.

Moreover, in many cases a supply of groundwater is present, originating from outside the irrigated field. This supply, which will be denoted as seepage, may cause considerable salinization, especially if the groundwater has a high salt content. Even in the humid climate of the Netherlands such a salinization may occur (Zuur, 1938).

A more quantitative description of the salinization is obtained by splitting up the movements of water and salts into movements occurring within the root zone and movements below this zone (fig. 1). Salinization occurs if more salt is added to the root zone than is removed, desalinization if the reverse is true. Therefore the salt balance of the root zone is of primary importance for describing these phenomena.

In the Netherlands this method has been developed by Zuur (1938) and Verhoeven (1953). Investigations made in the extremely arid climate of Iraq showed that also under these conditions the salt balance gives useful results (Dieleman et al., 1963). This method will be summarized here, with some minor modifications.

2. THE SALT BALANCE THEORY

The *water balance* of an irrigated soil is used as a starting point, as the salt-displacements are closely connected with the water-movements.

[1] Grontmij Land Reclamation Company, De Bilt, NETHERLANDS.

For a period of one month, the water balance of an irrigated soil reads:

$Ir + Pr = ET + P + \Delta V$ (1) liters/m²-month or mm/month with:

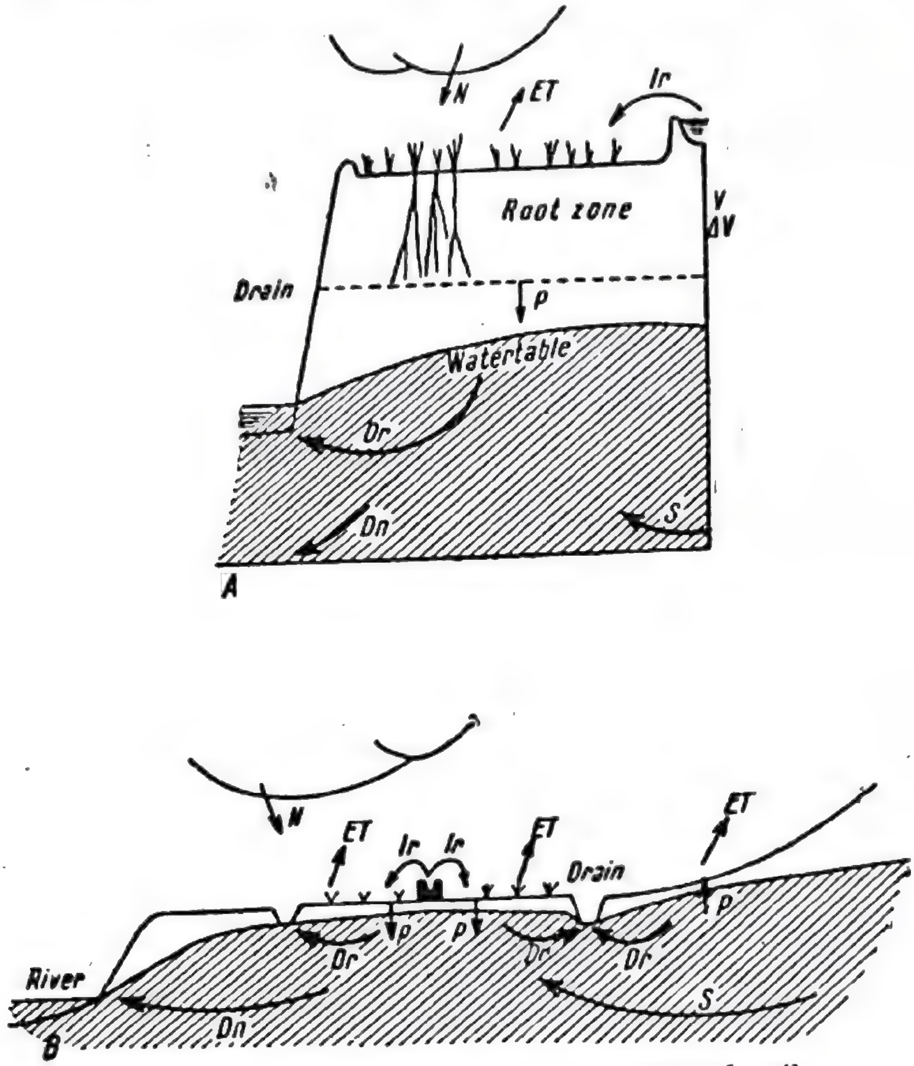

Fig. 1. Water-movements in an irrigated soil.

Ir	— amount of irrigation water penetrating into the soil	mm/month
Pr	— amount of precipitation water penetrating into the soil	„
ET	— evapotranspiration	„
P	— percolation from the root zone	„
	if negative: capillary rise into root zone	„
ΔV	— increase in soil moisture content of root zone	„
	if negative: decrease in soil moisture content	„
V	— amount of moisture stored in root zone	mm

For longer periods — say one year — the changes in soil moisture content ΔV can be supposed to be negligible.

If percolation occurs (positive values for P), the excess water has to be removed, either by natural drainage (Dn) or towards a system of drainage channels (Dr).

If capillary rise occurs (negative values for P), water is withdrawn from the subsoil. In some cases this removal is compensated by seepage supply from elsewhere (S).

The salt-balance is derived from the water-balance and reads:

$$Ir.\ C_{ir} + Pr.\ C_{pr} = P \cdot C_p + CR + \Delta Z \quad (2) \quad \text{me/m}^2 \text{ — month with:}$$

C_{ir}	— salt concentration in irrigation water	me/l
C_{pr}	— „ „ „ rainfall	„
C_p	— „ „ „ percolating water	„
CR	— amount of salt removed by the crop	me/m²—month
ΔZ	— changes in salt content of root zone	„
Z	— amount of salt in root zone	me/m²

In an irrigated soil the terms $Pr \cdot C_{pr}$ and CR can be neglected against the others, hence:

$$Ir \cdot C_{ir} = P \cdot Cp + \Delta Z \quad (3) \qquad \text{me/m}^2\text{—month}$$

Finally, the amount of salt at the end of a period (Z_2), as compared to the amount of salt at the beginning (Z_1) is:

$$Z_2 = Z_1 + \Delta Z \quad (4) \qquad \text{me/m}^2$$

or, as an average

$$\bar{Z} = \frac{Z_1 + Z_2}{2} = Z_1 + \frac{\Delta Z}{2} \quad (5) \qquad \text{me/m}^2.$$

In the balance, C_p, the salt concentration of the percolating water, is unknown, but it will be clear that it is related to the salt concentration in the soil moisture, C_{sm}.

To find C_{sm}, we suppose that the total amount of salt in the root zone, Z, is dissolved in the soil moisture V. The latter varies greatly, but we may suppose that the movements of water and dissolved salts are mainly restricted to periods when the soil is close to field capacity. They are especially occurring shortly after the irrigation of the field, when the amount of soil moisture is equal to V_{fc}.

In such periods, the average salt concentration in the root zone is:

$$C_{sm} = \frac{Z}{V_{fc}} \quad (6) \qquad \text{me/l}$$

or, averaged over one month:

$$C_{sm} = \frac{\bar{Z}}{V_{fc}} = \frac{Z_1}{V_{fc}} + \frac{\Delta Z}{2\,V_{fc}} \quad (7) \qquad \text{me/l}$$

For the salt concentration in the percolating water, C_p, different suppositions can be made:

a) $C_p = C_{\overline{sm}}$ (8) This is justified for soils loosing salts under the influence of a humid climate with low rainfall intensities (Verhoeven, 1953). For irrigated fields, however, the water movements are far less regular, and $C_p < C_{\overline{sm}}$. Boumans [(Dieleman et al., 1963)] introduced, therefore:

b) $C_p = f \cdot C_{\overline{sm}}$ (9) in which f is the efficiency of leaching. In Iraq this factor varied between 0.6 for light soils and 0.2 for heavy soils. The fact that $f < 1$ is caused by the presence of cracks in the soil, through which irrigation water passes without obtaining equilibrium with the soil moisture.

If the irrigation water contains appreciable amounts of salts, supposition (b) is no longer valid. In that case, the percolating water, P, may be considered as a mixture of unchanged irrigation water with concentration C_{ir} and soil moisture with concentration C_{sm} in the ratio $1-f$ to f. In that case is:

c)
$$C_p = C_{ir} + f(C_{\overline{sm}} - C_{ir}) \tag{10}$$

Combination of (3), (10), and (7) leads to the following expression for ΔZ:

$$\Delta Z = \frac{Q - R \cdot Z_1}{S}, \tag{11}$$

with:

$$\left.\begin{aligned} Q &= Ir - (1-f) \cdot P \cdot C_{ir} \\ R &= \frac{f \cdot P}{V_{fc}} \\ S &= 1 + 0.5\,R \end{aligned}\right\} \tag{12}$$

from which ΔZ can be predicted if the other quantities are known. By carrying out this computation for a number of consecutive months — preferably extending over a period of one year or more — it can be ascertained whether salinization or desalinization will occur under a given system of irrigation.

Moreover, the salt concentration in the soil moisture can be calculated at the end of each month from:

$$C_{\overline{sm}} = \frac{Z}{V_{fc}} \quad (13) \qquad \text{me/l}$$

In this way, it is possible to check whether these concentrations remain low enough to avoid damage to the crops. If this is not the case, larger amounts of water have to be given and consequently also the drainage requirements will be increased.

The salt concentrations $C_{\overline{sm}}$ can be expressed in terms of electrical conductivity of the saturation extract, EC_{ex}, as there is usually a linear

relationship between these two quantities. In many soils, the following approximate relationship may be used:

$$EC_{ex} \simeq \frac{C_{\overline{sm}}}{24} \quad (14) \qquad \text{mmhos/cm or mS/cm at } 25°\text{C}.$$

3. APPLICATION IN PRACTICE

With the salt balance equations given above, predictions can be made about the need for percolation under varying management, for irrigation waters of different quality and for crops with different salt tolerance. As appears from such computations, application of larger amounts of irrigation water results in lower salt concentrations in the soil, at least as long as adequate drainage is present. The need for percolation is greater as the water contains more soluble salts. For irrigation water of good quality the percolation losses occurring under normal management — usually 20—40 per cent of the amounts given to the field — are sufficient to secure a sufficiently low salt concentration in the root zone, as long as free drainage of the percolating water remains possible. But with poor quality waters- in many cases being the only kind available — more percolatiom is needed, which at the same time will make higher demands on the drainage system.

In most instances, however, a discharge capacity of 1—3 mm per 24 hours is sufficient for irrigated fields.

4. CAPILLARY RISE; THE INFLUENCE OF SEEPAGE

In general periods during which a field is irrigated, are not the most critical ones for salinization. Usually a downward water-current exists under such circumstances carrying away soluble salts. Far more dangerous are the periods when the field is left dry and capillary rise occurs (negative values of P). For such dry periods the same equations apply:

$$\Delta Z = \frac{Q - R \cdot Z_1}{S}, \tag{11 a}$$

with:

$$\left.\begin{aligned} Q &= O \text{ (no irrigation)} \\ R &= \frac{f \cdot P}{V_{fc}} \text{ (negative)} \\ S &= 1 + 0.5\ R\ (S < 1). \end{aligned}\right\} \tag{12 a}$$

During periods of capillary rise f is probably close to 1, as the larger pores — which cause the deviations during irrigated periods — do not contribute towards the capillary movements.

The amount of moisture transported by capillarity varies greatly. If no seepage occurs, this amount is usually limited to 20—50 mm during the dry

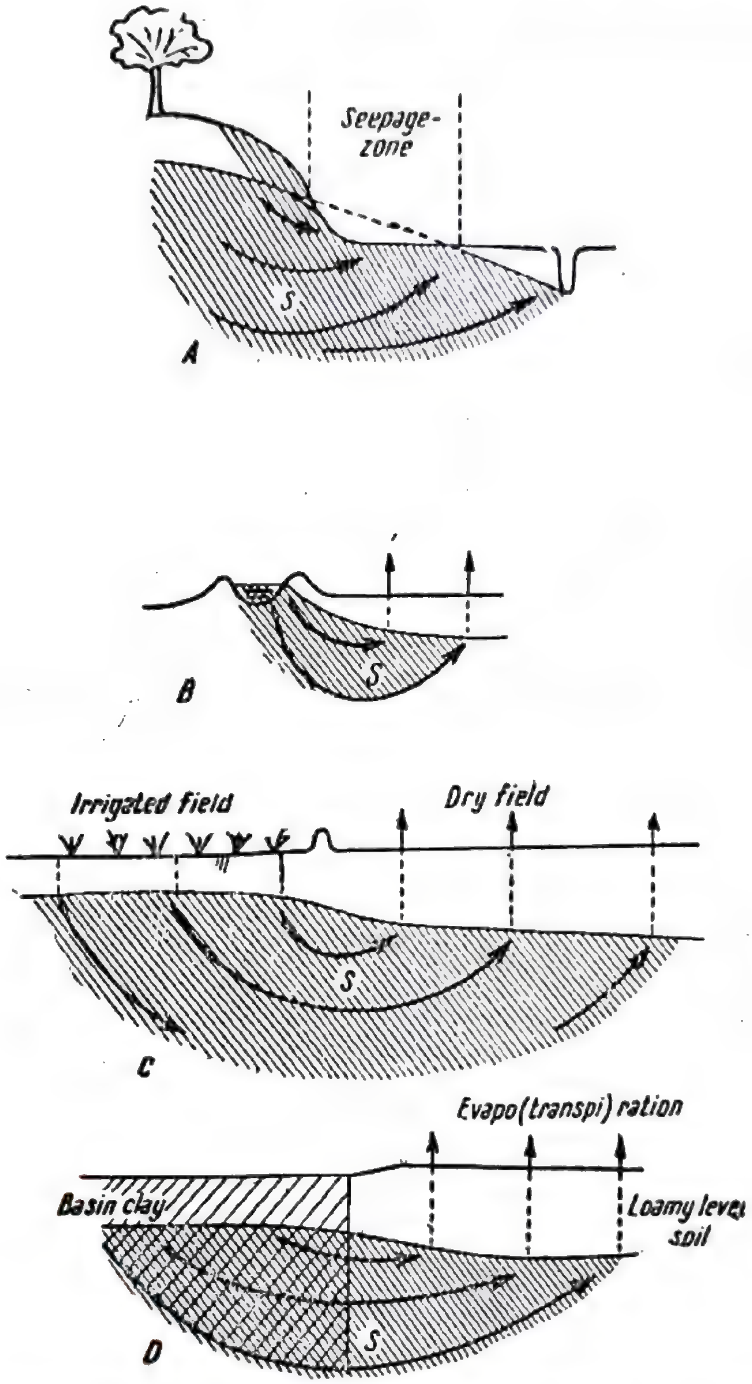

Fig. 2. Seepage in irrigated areas: *A.*—seepage from higher environments; *B.*—seepage from an irrigation canal; *C.*—seepage from an irrigated field; *D.*—seepage caused by differences in capillary characteristics of two adjacent soils.

season, but it may reach extremely high values if moisture is supplied by seepage-currents. Such seepage is extremely common in irrigated areas. Various conditions under which it occurs are indicated in figure 2.

One of the main tasks for a draiange system is therefore the control of such subsoil water currents. The depth of drainage necessary for preventing such currents from reaching the soil surface greatly depends upon the physical properties of the soil. The greatest depth is needed in soils showing a high capillarity, like silt loams and loess deposits. A smaller depth can be used for sandy soils (which have a limited capillary rise) as well as for many clay soils (in which the velocity of capillary movements is often extremely slow).

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SUMMARY

The method of calculating salt balances for irrigated soils is briefly discussed. From such balances the drainage requirements of irrigated soils can be derived. An important factor determining these requirements is seepage, which is a widespread phenomenon in irrigated areas.

RÉSUMÉ

La méthode de calculer les bilans de sels pour des sols irrigués est discutée brièvement. De tels bilans on peut déduire les besoins de drainage de sols irrigués. Un facteur important déterminant ces besoins est l'affluence de l'eau souterraine un phénomène se produisant fréquemment aux regions irriguées.

ZUSAMMENFASSUNG

Die Methode zur Berechnung von Salzbilanzen für bewässerten Böden wird in Kürze besprochen. Von solchen Bilanzen kann der Entwässerungsbedarf von Bewässerungsböden abgeleitet werden. Ein wichtiger, diesen Bedarf bestimmender Faktor ist die Sickerung des unterirdischen Wassers, ein in Bewässerungsgebieten häufig vorkommendes Phänomen.

DISCUSSION

K. DARAB (Ungarn). Alle vier Vorträge hatten eine gemeinsame Frage, nämlich alle vier beschäftigten sich mit der Rolle des Grundwassers bei der Alkalisierung der Böden.

Es ist klar, dass die Naturverhältnisse verschieden sind. Wir können aber bei diesen Prozessen einen gemeinsamen Grund finden. Dieser gemeinsame Grund ist die Salzbilanz der Böden. Der Charakter der Salzbilanz hängt von der Richtung der Salzbewegung im Bodenprofil ab

und diese ist bestimmend durch die Naturverhältnisse. Nach den Ergebnissen Dr. Rabotschews, erreichte man einen grossen Erfolg mit der Verbesserung der Salzböden in Kasachstan. Ich nehme an, Sie werden ein sehr gutes Entwässerungssystem ausbauen. Ich möchte gerne Dr. Rabotschew fragen, welche Faktoren zur Ausrechnung der kritischen Lage des Untergrundwassers, zu berücksichtigen sind wenn die kritische Lage des Untergrundwassers nicht vorhanden ist? In Zusammenhang mit dem Vortrag Herrn Krashevskis wollte ich bemerken, dass es nicht genügend ist die Leitfähigkeit oder Salzkonzentration des Untergrundwassers zu geben. Wir müssen auch die chemische Zusammensetzung in Betracht ziehen.

M. H. VAN DER MOLER. 1. Capillary rise is active over the following distances (very tentative figures):

Sands: 1.0—1.5 metres
Loess: 2—3,,
Clays: 1.5—2.0,,

2. Salinity of groundwater is not invariable, but is modified by amelioration and irrigation. Under systems of irrigation and drainage the initial groundwater is replaced by water which resembles the irrigation water in composition though it is more concentrated.

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GYPSUM ADSORPTION BY DIFFERENT SOILS OF THE UNITED ARAB REPUBLIC

A. H. I. MOUSTAFA [1]

INTRODUCTION

The black alkali soils in Egypt are distinguished from the fertile soils from which they have arisen by the dominance of exchangeable sodium, a high pH and by the marked increase in the insoluble calcium and magnesium compounds, the former being mainly as calcium carbonate and the latter as magnesium silicate. These soils are sticky and highly dispersed.

The proper reclamation of an alkali soil necessitates the displacement of a part of the exchangeable sodium. This can be achieved by the application of gypsum, sulphur, calcium chloride or any other soil correctives.

It is noteworthy that reclamation of the black alkali soil in Egypt is faced with many entanglements owing to the following facts:

1) the cation exchange capacity of soils is high; it ranges from about 36—45 m.e.%;

2) magnesium silicates precipitated during the process of alkalization help in obliterating the soil interstices and consequently calcium ions penetrate the soil with great difficulty.

In Egypt, there is much debate about the problem of gypsum, in respect with the quantity needed and time and depth of application. This work is a continuation to the study previously carried out by Moustafa and Shabassy (1959) and will deal with the chemical changes which soils undergo by gypsum treatment under different soil: water ratios.

MATERIAL AND EXPERIMENTS

Six alkali soil samples and five non-alkali soil samples were taken to represent different localities. The samples were dried, crushed and passed through a 2 mm sieve. Three dilutions of soil: water ratio were under investigation.

[1] General Director Soil Department, Ministry of Agriculture, Giza, U.A.R.

Tables 1, 2 and 3 show the analyses of these soil samples.

A. Experiment 1 (1 : 5, water ratio)

One hundred grams of soil together with the added gypsum were shaken continuously for one hour with 500 ml of distilled water. In the filtrate, conductivity, the cations and anions are estimated while the pH was estimated in the suspension. The treatments were as follows:

a) Soil + 0.0 gm of gypsum (control)
b) Soil + 0.2 gm of gypsum (2.33 me)
c) Soil + 0.4 gm of gypsum (4.65 me)
d) Soil + 0.8 gm of gypsum (9.30 me)
e) Soil + 1.2 gm of gypsum (13.95 me)
f) Soil + 1.6 gm of gypsum (18.60 me)
g) Soil + 2.00 gm of gypsum (23.26 me)

B. Experiment 2 (1 : 20, Soil: water ratio) 50 grams of soil together with the added gypsum were shaken continuously for one hour with 1000 ml of distilled water, and all the above estimations given above in experiment 1 were carried out in the filtrate. The treatments were as follows:

a) Soil + 0.0 gm of gypsum (control)
b) Soil + 0.1 gm of gypsum (1.16 me)
c) Soil + 0.2 gm of gypsum (2.33 me)
d) Soil + 0.4 gm of gypsum (4.65 me)
e) Soil + 0.8 gm of gypsum (9.30 me)
f) Soil + 1.2 gm of gypsum (13.95 me)
g) Soil + 1.6 gm of gypsum (18.60 me)
h) Soil + 2.0 gm of gypsum (23.26 me)
i) Soil + 2.4 gm of gypsum (21.91 me)
j) Soil + 3.2 gm of gypsum (37.21 me)
k) Soil + 4.0 gm of gypsum (46.51 me)

N.B.1 — The first four treatments in both experiments were carried on the non-alkali soils, while all the treatments were conducted on the alkali samples.
2. Chlorides were determined only in the control soils samples.

C. Experiment 3 (Soil Paste)

Gypsum was mixed thoroughly with 200 grams of soil, then a saturated paste was prepared and the pH is measured.

In the extract, conductivity and the forementioned cations and anions were determined, the treatments were as follows:

a) Soil + 0,00 gm of gypsum (control)
b) Soil + 0.203 gm of gypsum (2.36 me)
c) Soil + 0.508 gm of gypsum (5.91 me)
d) Soil + 1.015 gm of gypsum (11.8 me)
e) Soil + 1.523 gm of gypsum (17.71 me)
f) Soil + 2.03 gm of gypsum (23.6 me)
g) Soil + 3.045 gm of gypsum (35.41 me)
h) Soil + 4.06 gm of gypsum (47.21 me)
i) Soil + 5.75 gm of gypsum (59.01 me)

The mentioned treatments are roughly equivalent to 0, 2, 5, 10, 15, 20, 30, 40, and 50 tons respectively of gypsum added to the surface foot of a feddan.

ANALYTICAL METHODS

The methods used in the analytical determinations are as follows:

1. Mechanical analysis according to the Sudan decantation method.
2. Total soluble salts in experiments 1 and 2 were determined gravimetrically in the soil-water extract.
3. Anions and cations were determined in 1 : 5 and 1 : 20 soil: water extracts and saturation extracts, before and after gypsum treatments.
4. Electrical conductivity of the extracts was measured with a solubridge meter and recorded as millimhos/cm at 25°C.
5. Total carbonate was estimated by Collins'calcimeter.
6. Organic carbon was determined with the wet oxidation method of Walkley and Black.
7. Cation exchange capacity according to Hissink which was revised by Gracie et al. (1934).
8. Exchangeable sodium was determined in the original soil samples by the flame photometer.

ANALYTICAL DATA AND DISCUSSION

All the analytical data of the soils before treatments are given in tables 1,2 and 3. The analytical data of experiments 1—2 and 3 are shown in tables 4, 5 and 6 respectively.

1. *Soluble Carbonate and Bicarbonate*

Under chemical equilibrium, the reaction between gypsum and (CO_3^{--} + HCO_3^-) does not go to completion in all the treatments, both in alkali samples and in the non-alkali ones.

In all the three experiments the removal of the soluble CO_3 and HCO_3 is incomplete in the alkali samples even in the last treatments receiving high amounts of gypsum.

In figures 1, 2, 3, 4, 13 and 14, the sums of (CO_3^{--} + HCO_3^-) of tables 4, 5 and 6 are plotted against the quantities of gypsum added to the soil samples.

Referring to the figures of CO_3^{--}, HCO_3^- and Na^+ in the alkali soils, it is observed that the sodium increases from one treatment to another succesive one, and at the same time, the sum of (CO_3^{--} + HCO_3^-) decreases. Such results are in harmony with Kelley and Thomas (1923), Samuels (1927), Kelley and Arany (1928) and Moustafa and Shabassy (1959).

Generally speaking the decrease in (CO_3^{--} + HCO_3^-) by the increment of gypsum in the alkali soils is more marked in the first treatments than in the last ones in agreement with Moustafa and Shabassy (1959).

In the non-alkali soils 1, 2, 3, 4, and 5, no soluble carbonate appears in the water extract of the paste, 1 : 5 or 1 : 20. The HCO_3 decreases gradually with the increase of added gypsum, and their figures are markedly lower in the paste than in the 1 : 5 and 1 : 20 soil water extracts, probably due to the increase in the hydrolysis of the soil complex by dilution. Despite the fact that the bicarbonate in any treatment appears to be higher in the 1 : 20 soil extract than in the 1 : 5 and the latter is higher than in the paste extract.

2. *Exchangeable Sodium*

In figures 5, 6, 7, 8, 15 and 16 the exchangeable sodium in the soil samples treated with gypsum in the experiments is plotted against the quantities of gypsum added.

It can be observed, even in the treatments receiving heavy amounts of gypsum, that the ESP of the alkali samples No. 6, 8, 10 and 11 was 31, 20, 21 and 52 me per cent respectively, i.e. are still alkali according to Richards (1950). It is noteworthy that the exchangeable sodium of the alkali soils, with the exception of soil 6 is almost completely released by gypsum in the last treatment in experiment 2.

The sodium in the water extract of the alkali and non-alkali samples is always higher in the 1 : 20 then in the 1 : 5, soil : water ratio, in the same treatment, and the latter is higher than in the paste, this is due to the increase in the hydrolysis of the soil complex and to the increasing solubility of gypsum with the increase of water. In experiment 1 the sodium released from the complex by gypsum increases from one treatment to the successive one, whereas in experiment 2, it almost reaches a maximum at a certain treatment for each soil, beyond which the sodium on the soil complex is practically unaffected by the increment of gypsum; this holds good with experiment 3 with respect to alkali samples. This could be explained on the bases that the added gypsum in the last treatments in experiment 1 was not enough to release all the exchangeable Na from the soil complex while the gypsum added in experiment 2 was sufficient in the first treatments to release the majority of the exchangeable Na; in experiment 3 the ionization of gypsum due to the insufficient of water was almost the same in each of the last treatments.

The sodium released by gypsum from the complex of the non-alkali soil samples is in general small due to the negligible amounts of exchangeable Na in the soil. In all the experiments, the sandy soil No. 1 shows almost negligible amounts of released sodium. In experiment 3, the released sodium in the non-alkali soils increases gradually with the increment of gypsum from one treatment to the successive one.

3. *Exchangeable Magnesium*

In experiment 1 and 2, the exchangeable magnesium in the alkali soils is affected by the increase of added gypsum. In the filtrate of the alkali soils, the magnesium is almost negligible in the first treatments where there are considerable amounts of Na on the soil complex, while in the last treatments, in which sodium on the soil complex has been much reduced by gypsum, the magnesium is in relatively appreciable amounts. In the non- alkali soils 2, 3, 4 and 5, the magnesium in the filtrate is appreciably higher than in the alkali soils, and there is a gradual increase with the increment of gypsum. Accordingly, gypsum could be recommended to replace a part of the exchangeable magnesium. This has an important bearing on soils containing considerable content of exchangeable Mg such as those dealt with by Gracie and Moustafa (1931) who are of the opinion that magnesium confers on soils bad physical properties.

In experiment 3, the exchangeable magnesium in the alkali soils is slightly affected by the increment of gypsum. In the non alkali soils, the magnesium released does differ much from treatment to another successive one, though the released magnesium in these soils is somewhat higher than in the alkali ones.

4. *pH Value*

By the addition of gypsum CO_3^{--} and HCO_3^- are decreased and consequently the pH is decreased in the alkali and non-alkali soils.

5. *Calcium Consumed in Reaction*

In figures 9, 10, 11, 12, 17 and 18, the calcium consumed in reactions is plotted against the quantities of the gipsum added to the soil samples.

In both alkali and non-alkali soils, there is a significant difference (at 1 per cent level) between the different samples on one hand and between the treatments on the other hand. This could be partially due to the fact that the samples differ widely in their exchangeable Na contents and partially to the differences in the added gypsum. The calcium consumed in the non- alkali samples is lower than that in the alkali; due to their low content of exchangeable Na.

The correlation coefficient between the sulphate (of gypsum) in the saturation extract and the sum of exchangeable Na and (CO_3^{--} + HCO_3^-) present as soluble salts is highly significant. The coefficient of determination (r^2) indicates that 95 per cent of the variance in the solubility of gypsum in the soil paste could be accounted for by the mentioned sum, and the remaining 4 per cent of the variance is due to other factors. This above relationship between the mentioned sum and the gypsum solubility is positive and linear.

FACTORS AFFECTING GYPSUM ADSORPTION

1. *Exchangeable Sodium*

The preceding data showed that the gypsum reacts simultaneously on the soluble carbonate and bicarbonate and exchangeable Na.

In the last treatment of experiments 2 and 3 the correlation coefficient between the calcium consumed in reactions and the sum of the exchangeable Na and ($CO_3^{--} + HCO_3^-$) was calculated on the alkali soils and found to be 0.974 and 0.997 respectively. The coefficient of determinations are 0.949 and 0.994 respectively. These coefficients are statistically significant at 1 per cent level and indicate that 99 and 95 per cent of the variance in calcium consumption in experiments 2 and 3 could be accounted for by the sum of exchangeable Na and soluble ($CO_3^{--} + HCO_3^-$), the remaining 1 and 5 per cent is accounted for other factors such as exchangeable Mg, soluble salts, $CaCO_3$ and soil texture. Such relationship existing between the mentioned sum and the calcium consumption is positive and linear.

2. *Total Soluble Salts.*

The preceding data showed that the conductivity of the extracts in the three experiments, in the alkali and non-alkali samples, increases with the increment of gypsum.

To study statistically the effect of total soluble salts on gypsum adsorption, the correlation coefficients were computed between the salts per cent in the alkali samples and the calcium consumed in the reactions of the last treatments of the three experiments. These coefficients were 0.137, 0.176 and 0.310 respectively, indicating that the effect of the total soluble salts on the calcium consumed is statistically non-significant.

3. *Calcium Carbonate*

The $CaCO_3$ of the soil may react with the sodium exchange complex as follows:

$$2\,Na\,X + CaCO_3 \rightleftharpoons Ca\,X + Na_2CO_3$$

$$2\,Na\,X + Ca(HCO_3)_2 \rightleftharpoons Ca\,X + 2\,NaHCO_3$$

The partial pressure of CO_2 in the system is very important in this respect. In the alkali soils the concentration of sodium salts in solution is generally high and the presence of the calcium ions (from $CaCO_3$) in solution is very small and will not compete with the sodium ions in entering the soil complex. Moreover, the gypsum added to the soil samples depresses the dissociation of $CaCO_3$ by common ion effect. According to the above mentioned, the effect of $CaCO_3$ on gypsum adsorption is expected to be small. The sta-

tistical study showed that the effect of $CaCO_3$ on the calcium consumption is non-significant. This result does not deprive $CaCO_3$ from being of great value under field condition in soil reclamation.

4. *Soil Texture*

The effect of soil texture on gypsum adsorption is manifested only in the sandy soil No. 1. The correlation coefficients between calcium consumed in the last treatments of experiment 2 and 3 of the alkali samples were 0.653 and 0.581 respectively, which are considered to be statistically, non-significant. This may be due to the fact that the effect of texture on calcium consumption was overshadowed by the presence of considerable amounts of exchangeable Na in the different soil samples.

5. *Effect of Dilution on the Reactions*

The preceding data indicate that the soil water ratio has an effect on the reactions. Comparison of the three dilution showed that the increase in (CO_3^{--} + HCO_3^-) from the paste to 1 : 5 to 1 : 20 ratios is significantly higher in the alkali samples than in the non-alkali ones. This result is considered to be of great importance in the diagnosis of alkali soils. The sodium in the water extract of the 1 : 20 is higher than of the 1 : 5 in the same treatment in both alkali and non-alkali soils; this is partially due to the increase in the hydrolysis of the complex with dilution and partially to increase in gypsum solubility with the increment of water. The dilution effect on conductivity is very clear. The conductivity in experiement 2 in both the alkali and non-alkali samples is always higher than one fourth of the conductivity in experiment 1. The pH increases with the increase of water: soil ratio. This is due to increase in hydrolysis of the complex, the result of which is an increase in dissociation of sodium.

Table 1

Mechanical Analysis of the Soil Samples
(figures reported as gm. per cent oven — dry soil)

Soil No.	Locality	Coarse sand	Fine Sand	Silt	Clay
1	Anshas	77.5	21.3	0.4	0.8
2	El Talbia	26.3	30.9	10.1	32.7
3	Giza	2.9	38.7	22.6	35.8
4	Mataana-1	1.3	16.4	31.6	50.7
5	Mataana — 2	0.8	13.4	25.7	60.1
6	Kafr El Zayat	0.4	39.1	34.7	25.8
7	Tal El Kebir — 1	7.4	14.8	8.2	69.6
8	Tal El Kebir — 2	26.9	14.7	25.4	33.0
9	Hosh Isa-6	29.4	35.6	6.0	29.0
10	Hosh Isa-7	29.8	38.7	5.7	25.8
11	Tal El Kebir-3	26.0	18.9	21.5	33.6

Table 2

Calcium Carbonate, Organic Matter and Soluble Salts in the Soil Samples

Soil No.	$CaCO_3$ %	Organic Matter %	Total Soluble Salts	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+
				in me %						
1	0.03	0.03	0.06	0.00	0.43	0.29	0.28	0.33	0.10	0.65
2	3.11	0.79	0.28	0.00	1.70	1.89	0.86	0.81	0.90	3.30
3	2.79	1.30	0.20	0.00	1.49	1.59	0.46	0.60	0.71	2.60
4	2.48	0.73	0.15	0.00	1.51	0.75	0.30	0.61	0.40	1.65
5	2.25	0.94	0.16	0.00	1.50	0.79	0.39	0.81	0.36	1.66
6	3.62	0.84	0.60	4.61	3.35	0.74	2.07	0.24	0.33	10.40
7	14.57	1.02	0.60	4.50	6.70	2.90	0.34	Tr.	Tr.	14.10
8	8.13	0.29	0.91	6.80	3.70	3.47	2.19	0.15	Tr.	18.50
9	6.73	0.34	1.56	2.51	3.65	11.85	5.62	0.43	0.32	23.20
10	6.52	0.41	2.15	4.69	3.86	21.20	6.56	0.43	0.15	37.00
11	7.32	0,40	3.37	16.08	4.76	25.20	13.64	0.30	Tr.	60.00

Table 3

Cation Exchange Capacity, Exchangeable Bases and ESP in the Soil Samples

Soil no.	Cat. Ex. Cap.	Exch. Ca	Ex. Mg	Ex. Na	ESP
		in me %			
1	1.16	0.55	0.34	0.10	8.6
2	36.00	25.50	7.90	0.60	1.7
3	38.00	29.20	7.61	0.75	2.0
4	49.20	37.75	9.30	0.40	0.8
5	51.60	40.48	9.40	0.40	0.8
6	25.00	1.26	2.88	21.00	84.0
7	40.50	1.10	Tr.	38.00	93.8
8	29.70	0.50	1.68	27.00	90.9
9	17.92	1.13	0.80	15.00	83.7
10	18.80	0.93	1.65	16.00	85.1
11	30.80	1.00	0.58	28.80	93.5

Table 4

Analytical Data of Experiment 1 (Soil : water ratio = 1 : 5)

Soil No.	Treat-ment No.	pH	Cond. in mmhos/cm. at 25°C	CO_3^{--}	HCO_3^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^{++}	Ca^{++} consumed in reactions
				in me %						
1	a	8.65	0.160	0.00	0.23	0.20	0.11	0.05	0.38	
	b	8.20	0.702	0.00	0.15	2.58	2.11	0.22	0.55	0.38
	c	7.80	1.087	0.00	0.14	5.00	4.37	0.31	0.60	0.54
	d	7.65	1.826	0.00	0.12	9.37	8.64	0.34	0.64	0.64
2	a	8.15	0.530	0.00	0.70	0.74	0.43	0.34	1.10	
	b	7.80	0.910	0.00	0.50	3.05	3.07	0.98	1.36	1.27
	c	7.75	1.230	0.00	0.43	5.25	3.10	1.42	1.50	1.84
	d	7.60	1.850	0.00	0.35	9.67	6.81	2.19	1.56	2.55
3	a	8.22	0.466	0.00	0.56	0.38	0.50	0.37	1.43	
	b	8.08	0.867	0.00	0.41	2.69	1.71	1.11	1.80	1.10
	c	7.96	1.224	0.00	0.35	4.91	3.31	1.63	1.88	1.72
	d	7.88	1.809	0.00	0.31	9.40	6.76	2.60	1.93	2.76
4	a	8.40	0.332	0.00	0.54	0.18	0.42	0.33	0.96	
	b	8.00	0.779	0.00	0.40	2.47	1.78	0.65	1.15	0.93
	c	7.92	1.141	0.00	0.37	4.76	3.36	1.63	1.20	1.64
	d	7.78	1.794	0.00	0.32	9.55	6.76	2.64	1.23	3.03
5	a	8.30	0.388	0.00	0.47	0.22	0.64	0.30	0.90	
	b	8.00	0.695	0.00	0.44	2.48	2.18	0.66	1.10	0.72
	c	7.95	1.014	0.00	0.40	4.79	4.09	1.09	1.20	1.12
	d	7.85	1.544	0.00	0.40	9.41	7.62	1.78	1.20	2.21
6	a	10.00	1.304	1.05	2.17	1.36	Tr.	Tr.	5.85	
	b	9.77	1.576	0.65	1.47	3.64	0.16	Tr.	7.14	2.12
	c	9.65	1.850	0.40	1.33	5.78	0.19	0.11	8.75	4.23
	d	9.45	2.640	0.15	0.80	10.33	0.50	0.13	11.50	8.47
	e	9.10	3.420	Tr.	0.82	15.13	1.84	0.16	15.00	11.93
	f	8.80	4.150	0.00	0.68	19.14	3.91	0.27	16.25	13.87
	g	8.80	4.600	0.00	0.63	23.19	7.17	0.41	16.75	14.66
7	a					0.21	Tr.			
	b					2.61	0.15			2.25
	c					4.96	0.20			4.55
	d					9.85	0.25			9.39
	e					14.10	0.55			13.34
	f					18.94	1.14			17.59
	g					23.52	2.34			20.97
8	a	10.20	2.380	6.03	1.89	2.09	0.13	Tr.	16.25	
	b	10.10	2.457	4.04	1.53	4.47	0.15	Tr.	16.38	2.36
	c	9.95	2.826	2.77	1.61	6.68	0.17	Tr.	17.50	4.45
	d	9.80	3.463	1.65	1.46	11.53	0.25	Tr.	20.63	9.32
	e	9.60	4.189	1.50	1.27	16.09	0.73	0.09	25.00	13.40
	f	9.40	5.585	1.05	1.09	20.87	1.73	0.08	28.13	17.18
	g	9.22	6.199	0.90	0.94	25.62	3.23	0.22	30.60	20.43
9	a	9.91	3.543	0.92	1.33	5.01	0.14	0.07	19.40	
	b	9.78	3.884	0.59	0.97	7.49	0.20	0.10	21.25	2.42
	c	9.39	5.128	0.21	0.69	9.74	0.25	0.30	23.00	4.62

Table 4 (continued)

Soil no.	Treatment no.	pH	Cond. in mmhos/cm. at 25°C	CO_3^{--}	HCO_3^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	Ca^{++} consumed in reactions
				in me%						
9	d	9.10	5.373	0.10	0.56	14.33	1.38	0.38	25.50	7.92
	e	9.05	5.480	0.04	0.43	18.82	3.05	0.49	28.50	10.90
	f	8.85	6.012	0.04	0.42	23.27	5.84	0.58	30.00	12.56
	g	8.75	6.437	0.00	0.40	27.57	8.77	0.70	31.50	13.93
10	a	10.18	5.586	2.62	1.68	6.07	0.10	0.06	32.00	
	b	10.12	5.746	2.28	1.47	8.55	0.18	0.11	34.00	2.40
	c	10.03	5.980	1.89	1.34	10.85	0.30	0.14	35.75	4.58
	d	9.75	6.682	1.04	1.03	14.79	0.97	0.16	37.50	7.85
	e	9.45	7.129	0.37	0.79	18.84	2.34	0.29	39.50	10.53
	f	9.13	7.608	0.29	0.59	23.34	4.62	0.58	41.50	12.75
	g	9.05	8.033	0,17	0.53	27.38	7.82	0.56	42.00	13.59
11	a	10.30	7.792	16.87	1.89	13.00	0.30	Tr.	57.60	
	b	10.25	7.908	14.88	1.99	15.30	0.35	Tr.	58.00	2.25
	c	10.20	8.025	14.14	0.68	17.65	0.39	Tr.	58.40	4.56
	d	10.10	8.141	9.22	1.15	22.35	0.40	Tr.	58.80	9.25
	e	9.95	8.292	5.55	1.10	26.95	0.54	Tr.	59.40	13.71
	f	9.75	8.664	2.93	1.15	31.62	0.83	0.10	60.40	18.22
	g	9.45	8.781	1.57	0.79	35.81	1.36	0.12	62.80	21.75

Table 5

Analytical Data of Experiment 2 (Soil : water ratio = 1 : 20)

Soil No.	Treatment No.	pH	Cond. in mmhos/cm. at 25°C	CO_3^{--}	HCO_3^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	Ca^{++} consumed in reaction
				in me %						
1	a	7.60	0.060	0.00	0.43	0.28	0.33	0.10	0.65	
	b	7.10	0.204	0.00	0.34	2.59	2.24	0.35	0.70	0.40
	c	7.00	0.340	0.00	0.32	5.02	4.60	0.33	0.75	0.47
	d	7.00	0.585	0.00	0.31	9.40	8.85	0.50	0.75	0.60
2	a	8.45	0.291	0.00	1.70	0.86	0.81	0.90	3.30	
	b	8.28	0.470	0.00	1.50	3.14	2.24	1.36	3.45	0.85
	c	8.10	0.642	0.00	1.40	5.52	3.76	1.70	3.95	1.71
	d	7.80	0.975	0.00	1.30	10.09	7.11	2.92	4.10	2.93
3	a	8.98	0.187	0.00	1.49	0.46	0.60	0.71	2.60	
	b	8.65	0.325	0.00	1.19	2.88	2.24	0.87	2.80	0.78
	c	8.35	0.480	0.00	1.05	5.07	3.66	1.42	3.00	1.55
	d	8.23	0.734	0.00	0.92	9.67	7.01	2.23	3.10	2.80
4	a	8,86	0.125	0.00	1.51	0.30	0.61	0.40	1.65	
	b	8.30	0.266	0.00	1.26	3.05	2.44	0.85	1.75	0.92
	c	8.02	0.404	0.00	1.26	3.52	3.51	1.86	1.90	2.32
	d	8.00	0.636	0.00	1.22	9.66	7.40	2.71	1.90	2.57

Table 5 (continued)

Soil No.	Treatment No.	pH	Cond. in mmhos/cm. at 25°C	CO_3^{--}	HCO_3^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	Ca^{++} consumed in reactions
				in me %						
5	a	8.63	0.144	0.00	1.50	0.39	0.81	0.36	1.66	
	b	8.20	0.257	0.00	1.40	2.78	2.64	0.78	1.75	0.56
	c	8.10	0.365	0.365	1.36	5.09	4.20	1.04	1.86	1.31
	d	7.85	0.581	0.00	0.94	9.73	7.82	1.92	1.90	2.33
6	a	10.30	0.573	4.61	3.35	2.07	0.24	0.33	10.40	
	b	10.05	0.626	3.96	2.72	4.08	0.50	0.57	11.12	1.75
	c	9.90	0.695	2.64	3.14	6.03	0.60	0.63	11.72	3.60
	d	9.50	0.817	1.32	2.94	10.62	0.60	0.67	14.25	8.19
	f	8.95	1.290	0.22	1.68	19.79	2.99	0.93	18.56	14.97
	h	8.73	1.723	Tr.	1.30	29.35	9.06	0.99	21.20	18.46
	i	8.58	2.064	Tr.	1.20	38.93	16.92	2.08	21.20	20.18
	j	8.50	2.415	Tr.	1.20	46.74	24.88	2.74	21.20	20.03
	k.	8.42	2.766	Tr.	1.10	36.29	34.14	2.59	21.60	20.32
	l	8.25	3.375	1.00	0.10	68.35	45.21	3.00	22.20	21.31
	m	8.10	3.575	0.00	1.00	73.80	50.56	3.29	22.60	21.41
7	a					0.34	Tr.			
	b					2.71	0.30			2.07
	e					5.00	0.40			4.26
	d					9.80	0.50			8.96
	f					19.00	1.00			17.66
	h					28.20	1.99			25.87
	i					37.46	6.37			30.75
	j					47.07	14.73			32.00
	k					56.08	22.49			33.25
	l					74.57	38.82			35.41
	m					86.63	49.17			37.17
8	a	10.30	0.639	6.80	3.70	2.19	0.15	Tr.	18.50	
	b	10.20	0.645	5.60	3.70	4.52	0.47	Tr.	19.00	2.01
	c	10.05	0.650	4.40	2.80	6.79	0.54	Tr.	19.50	4.21
	d	9.95	0.860	1.80	2.60	11.75	0.54	Tr.	21.26	9.17
	f	9.62	1.688	1.40	2.40	21.18	1.06	0.12	29.00	18.08
	h	9.37	2.070	1.20	1.80	30.23	4.77	0.18	34.00	23.42
	i	9.22	2.408	1.00	1.30	39.58	12.18	0.20	35.50	25.36
	j	9.18	2.723	1.00	0.80	49.01	19.91	0.20	36.20	27.06
	k	9.15	3.116	0.80	0.80	57.13	27.50	0.50	36.20	27.59
	l	9.02	3.679	0.60	0.90	74.85	45.09	0.95	36.20	27.72
	m	8,90	3.789	0.60	0.90	82.39	52.00	1.29	36.20	28.35
9	a	10.15	1.170	2.51	3.65	5.62	0.43	0.32	23.20	
	b	10.00	1.224	1.42	3.35	8.15	0.61	0.36	24.40	2.35
	c	9.95	1.298	1.26	2.51	10.44	0.81	0.50	25.60	4.44
	d	9.68	1.479	0.67	1.76	14.70	1.48	0.58	28.00	8.03
	f	9.15	2.128	Tr.	1.51	23.67	5.89	0.57	31.20	12.59
	h	9.00	2.500	Tr.	1.42	32.97	13.82	0.71	32.40	13.96
	i	8.78	2.788	Tr.	1.05	42.30	22.76	0.72	32.40	14.35
	j	8.70	3.149	0.00	1.03	51.51	31.70	0.72	32.40	14.62
	k	8.68	3.447	0.00	1.01	60.88	40.44	0.76	33.20	15.25
	l	8.52	3.937	0.00	0.84	76.26	55.68	1.01	33.20	15.39
	m	8.30	4.183	0.00	0.80	78.37	56.90	0.96	33.60	16.28

Table 5 (continued)

Soil No.	Treatment No.	pH	Cond. in mmhos./cm. at 25°C.	CO_3^{--} (me %)	HCO_3^- (me %)	SO_4^{--} (me %)	Ca^{++} (me %)	Mg^{++} (me %)	Na^+ (me %)	Ca^{++} consumed in reactions (me %)
10	a	10.36	1.739	4.69	3.86	6.56	0.43	0.15	37.00	
	b	10.28	1.826	3.56	3.33	8.94	0.47	0.21	37.60	2.34
	c	10.16	1.902	2.72	3.08	11.24	0.71	0.28	39.00	4.40
	d	9.98	2.087	2.72	1.84	15.90	1.02	0.31	42.00	8.75
	f	9.77	2.404	1.20	1.70	24.04	4.84	0.60	44.50	13.07
	h	9.48	2.704	0.96	1.32	33.63	11.58	0.60	46.00	15.92
	i	9.28	3.024	0.80	1.14	42.97	20.52	0.61	46.00	16.32
	j	9.20	3.302	0.72	1.08	50.59	28.04	0.80	46.00	16.42
	k	9.13	3.633	0.68	1.06	59.03	36.38	0.81	46.00	16.52
	l	9.09	4.066	0.64	1.08	76.64	54.25	0.93	45.60	16.26
	m	8.90	4.320	0.60	1.10	79.65	57.10	1.85	45.60	16.42
11	a	10.40	2.607	16.08	4.76	13.64	0.30	Tr.	60.00	
	b	10.38	2.670	16.48	3.32	15.87	0.39	Tr.	61.60	2.14
	c	10.35	2.690	15.28	3.63	18.30	0.52	Tr.	62.40	4.44
	d	10.35	2.726	13.44	3.08	22.76	0.72	0.05	64.80	8.70
	f	10.31	3.544	10.72	2.92	32.18	1.62	0.14	70.00	17.22
	h	10.12	3.656	6.48	2.40	41.23	3.52	0.13	72.50	24.37
	j	9.82	3.915	3.20	2.16	50.41	5.96	0.12	75.00	31.11
	j	9.55	4.185	1.28	2.28	59.97	11.60	0.31	77.50	35.03
	k	9.40	4.556	0.96	2.04	66.18	16.20	0.41	78.00	36.64
	l	9.10	5.006	0.80	1.68	84.68	33.30	0.53	78.75	38.04
	m	9.00	5.100	0.64	1.68	88.52	36.51	0.64	79.00	38.67

Table 6

Analytical Data of Experiment 3 (Soil Paste)

Soil No.	Treatment No.	Water added (in c.c. %)	pH	Cond. in mmhos./cm. at 25°C.	CO_3^{--} (in me %)	HCO_3^- (in me %)	Cl^- (in me %)	SO_4^{--} (in me %)	Ca^{++} (in me %)	Mg^{++} (in me %)	Na^+ (in me %)	Ca^{++} consumed in reactions (in me %)
1	a	23.0	7.55	2.310	0.00	0.13	0.23	0.20		0.05	0.46	
	b	23.0	7.50	4.530	0.00	0.07		1.09		0.05	0.69	0.29
	c	23.0	7.45	4.650	0.00	0.07		1.11		0.06	0.68	0.30
2	a	49.0	7.65	3.200	0.00	0.30	0.78	0.16	0.34	0.26	0.64	
	b	49.0	7.60	4.140	0.00	0.21		1.40	1.07	0.30	1.02	0.51
	c	49.0	7.55	4.760	0.00	0.21		2.21	1.51	0.30	1.61	0.88
3	a	56.0	7.85	2.740	0.00	0.49	0.86	0.22	0.28	0.53	0.76	
	b	55.0	7.60	4.550	0.00	0.46		1.40	1.20	0.60	0.92	0.26
	c	57.0	7.55	5.050	0.00	0.45		2.98	1.82	0.60	1.87	1.22
4	a	65.5	7.65	1.160	0.00	0.40	0.44	0.18	0.34	0.28	0.40	
	b	65.0	7.60	2.230	0.00	0.33		1.35	0.86	0.32	0.94	0.65
	c	65.0	7.50	3.340	0.00	0.29		2.53	1.90	0.35	0.99	0.79
5	a	70.5	7.65	1.250	0.00	0.47	0.45	0.19	0.32	0.30	0.49	
	b	70.0	7.60	2.570	0.00	0.32		1.38	1.39	0.35	0.41	0.12
	c	70.0	7.60	3.760	0.00	0.32		2.52	2.16	0.35	0.78	0.49

Table 6 (continued)

Soil No.	Treatment No.	Water added (in c.c. %)	pH	Cond. in mmhos./cm. at 25°C	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	Ca^{++} consumed in reactions
					in me %							
6	a	55.0	9.40	6.140	0.13	0.79	0.41	1.11	0.06	Tr.	2.38	
	b	55.0	9.20	8.460	0.06	0.73		2.28	0.12	Tr.	3.36	1.11
	c	53.5	9.15	10.680	0.04	0.56		4.15	0.30	Tr.	4.86	2.80
	d	54.0	9.10	12.460	0.03	0.47		7.08	0.82	0.07	7.10	5.21
	e	54.0	8.95	14.690	0.03	0.39		8.19	1.30	0.10	7.62	5.84
	f	53.5	8.80	14.800	0.03	0.37		8.30	1.44	0.10	7.57	5.81
	g	54.0	8.70	15.130	0.02	0.39		8.56	1.67	0.17	7.54	5.84
	h	54.0	8.60	16.020	0.02	0.39		8.84	1.64	0.20	7.82	6.15
7	f	93.5	8.70	12.500	Tr.	0.46		12.08	2.06	Tr.		10.76
	g	93.5	8.60	16.700	Tr.	0.45		17.18	2.55	Tr.		14.63
	h	94.0	8.50	17.500	Tr.	0.44		18.09	3.40	Tr.		14.69
	i	93.5	8.40	18.200	Tr.	0.41		18.56	3.84	Tr.		14.72
8	a	138.0	9.90	8.469	2.69	0.55	3.22	2.10	0.07	Tr.	7.59	
	b	135.0	9.75	8.917	1.64	0.68		3.26	0.09	Tr.	8.71	1.14
	c	132.0	9.50	10.680	0.99	0.59		5.03	0.11	Tr.	9.72	2.89
	d	120.0	9.25	14.418	0.53	0.70		7.66	0.27	0.02	11.82	5.36
	e	120.0	8.95	17.622	0.22	0.38		9.55	0.68	0.04	12.65	6.77
	f	115.0	8.60	19.758	Tr.	0.43		12.24	1.38	0.11	14.40	8.83
	g	112.0	8.35	21.894	Tr.	0.34		15.10	2.54	0.28	15.84	10.53
	h	109.0	8.30	22.428	Tr.	0.33		16.35	2.54	0.30	17.06	11.78
	i	109.0	8.20	22.748	Tr.	0.31		17.54	2.58	0.29	18.20	12.93
9	a	51.0	9.00	18.860	0.28	0.39	9.12	4.98	0.08	Tr.	14.69	
	b	51.0	8.85	19.800	0.10	0.34		6.16	0.22	Tr.	15.50	1.04
	c	49.0	8.75	21.220	0.08	0.24		7.64	0.40	0.10	16.58	2.34
	d	49.0	8.55	24.990	0.06	0.29		10.69	1.21	0.15	18.70	4.58
	e	49.0	8.50	25.460	0.04	0.21		10.79	1.27	0.27	18.62	4.62
	f	48.5	8.45	25.760	0.03	0.22		10.85	1.35	0.30	18.57	4.60
	g	48.5	8.45	25.930	0.02	0.22		10.95	1.37	0.32	18.62	4.68
	h	48.5	8.40	26.50	0.02	0.21		11.01	1.39	0.33	18.64	4.72
10	a	49.0	9.50	32.060	2.26	0.90	15.35	5.93	0.06	Tr.	24.38	
	b	49.5	9.35	33.010	1.55	0.88		7.02	0.10	Tr.	24.70	1.05
	c	49.5	9.20	35.830	0.67	0.62		19.01	0.25	Tr.	25.40	2.89
	d	49.0	9.00	41.960	0.10	0.31		12.01	0.59	0.08	27.10	5.55
	e	47.5	8.85	42.910	0.06	0.22		12.95	1.50	0.09	26.79	5.58
	f	47.0	8.80	43.380	0.04	0.21		13.33	1.81	0.13	26.99	5.65
	g	47.0	8.70	43.650	0.03	0.22		13.82	1.80	0.20	27.42	6.15
	h	47.0	8.60	44.270	0.03	0.22		14.05	1.87	0.25	27.53	6.38
11	a	58.5	10.50	83.858	13.82	0.23	16.25	12.79	Tr.	Tr.	43.09	
	b	58.5	10.40	83.850	12.89	1.90		13.87	0.03	Tr.	44.08	1.05
	c	58.5	10.15	84.906	10.69	1.50		15.75	0.05	Tr.	44.14	2.91
	d	57.5	9.90	84.916	8.73	1.48		18.39	0.06	Tr.	44.79	5.54
	e	57.5	9.80	85.760	7.01	0.77		20.54	0.07	0.01	44.49	7.68
	f	57.0	9.70	93.450	4.63	1.08		22.80	0.10	0.03	44.63	9.91
	g	56.0	9.65	93.500	1.55	0.43		27.32	0.17	0.09	45.29	14.36
	h	54.0	9.25	96.120	0.10	0.17		31.19	1.41	0.25	46.05	16.99
	i	54.0	8.65	97.508	Tr.	0.23		31.27	1.45	0.21	46.09	16.98

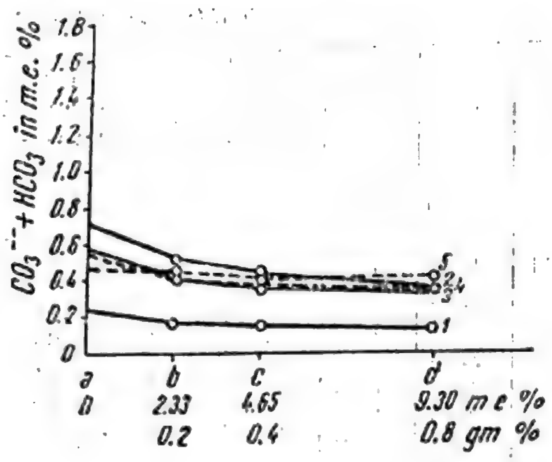


Fig. 1. Effect of Gypsum Treatment on Soluble Carbonate and Bicarbonate in the Non Alkali Soil Samples in Experiment 1 (1 :5).

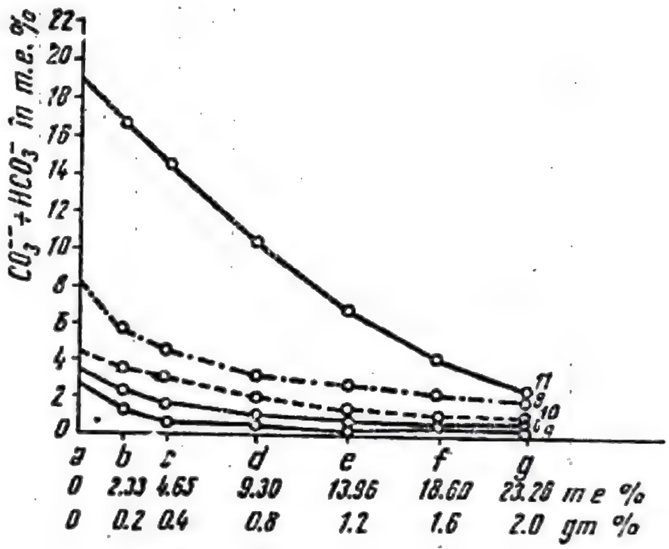


Fig. 2. Effect of Gypsum Treatment on Soluble Carbonate and Bicarbonate in the Alkali Soil Samples in Experiment 1 (1 :5).

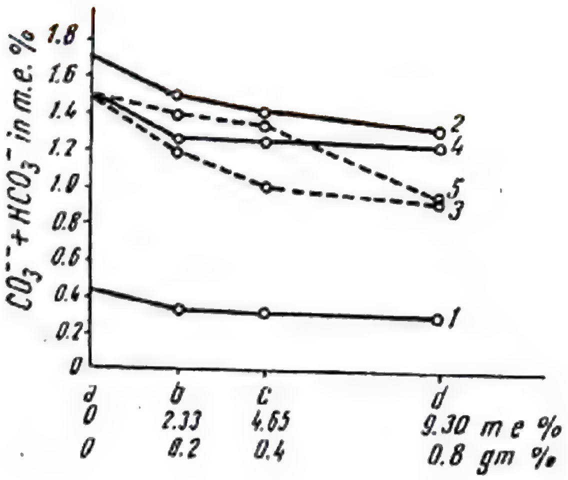


Fig. 3. Effect of Gypsum Treatment on Soluble Carbonate and Bicarbonate in the Non-Alkali Soil Samples in Experiment 2 (1 :20).

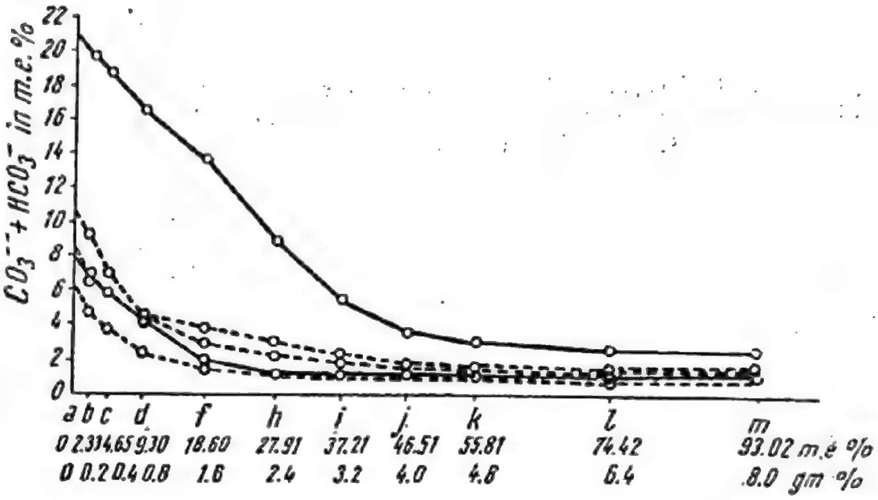


Fig. 4. Effect of Gypsum Treatment on Soluble Carbonate and Bicarbonate in the Alkali Soil Samples in Experiment 2 (1 :20).

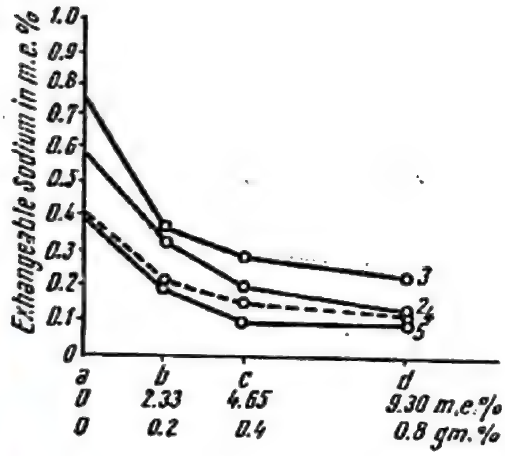


Fig. 5. Effect of Gypsum Treatment on Exchangeable Sodium in the Non-Alkali Soil Samples in Experiment 1 (1 :5).

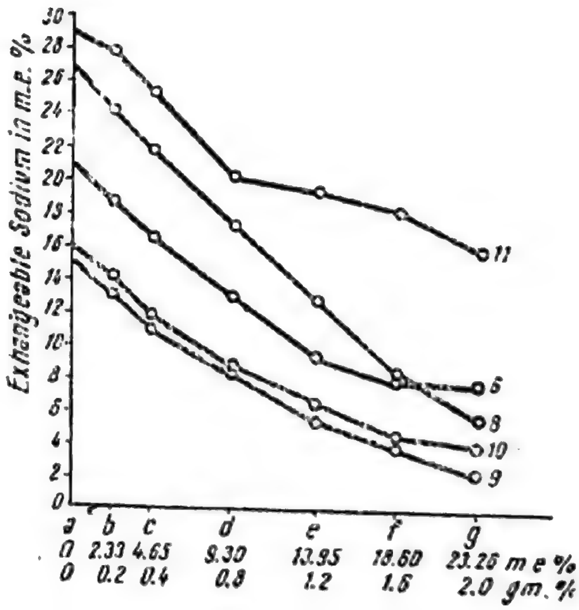


Fig. 6. Effect of Gypsum Treatment on Exchangeable Sodium in the Alkali Soil Samples in Experiment 1 (1 :5).

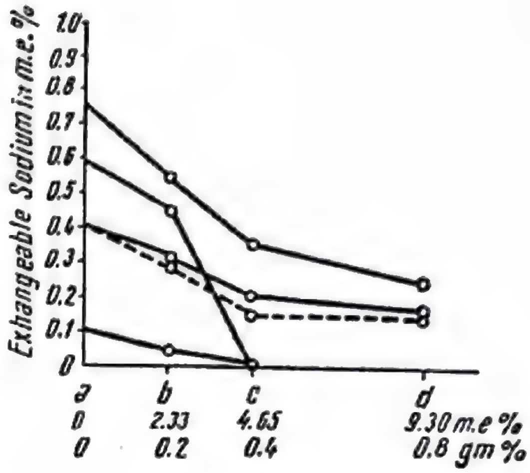


Fig. 7. Effect of Gypsum Treatment on Exchangeable Sodium in the Non-Alkali Samples in Experiment 2 (1 :20).

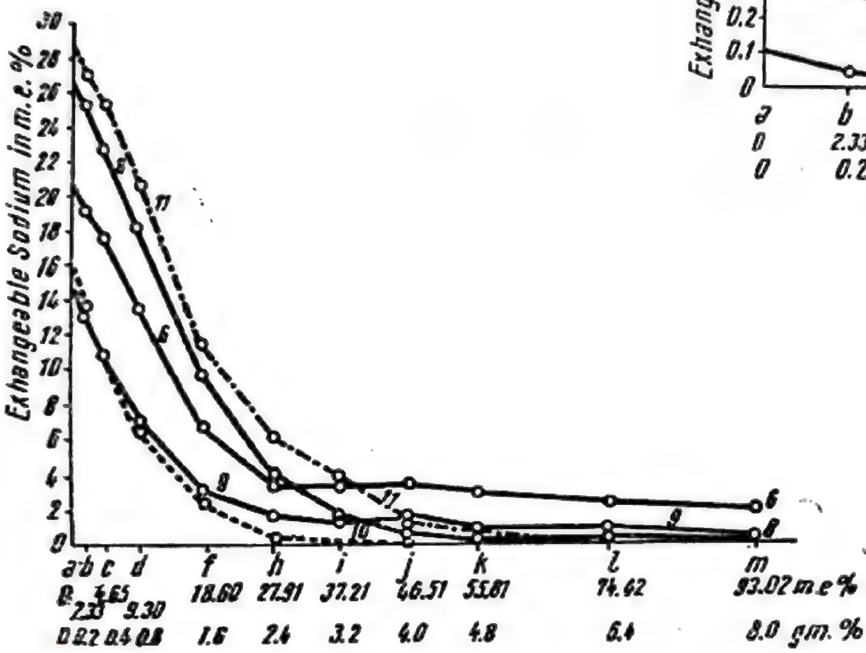


Fig 8. Effect of Gypsum Treatment on Exchangeable Sodium in the Alkali Soil Samples in Experiment 2 (1 :20).

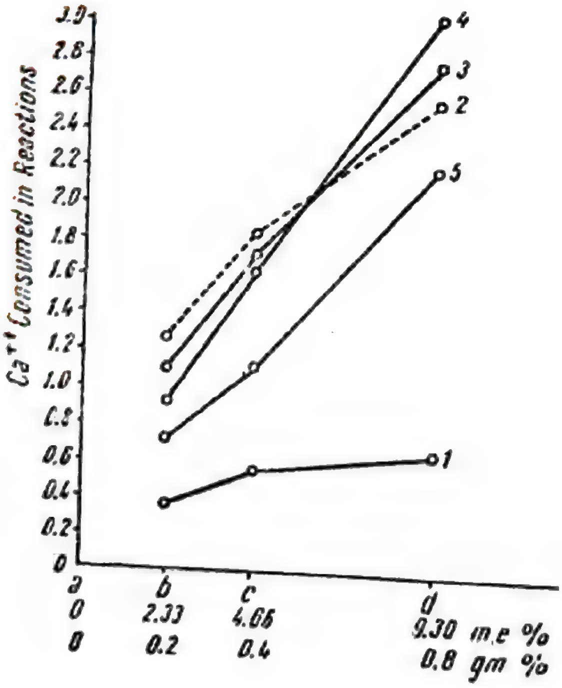
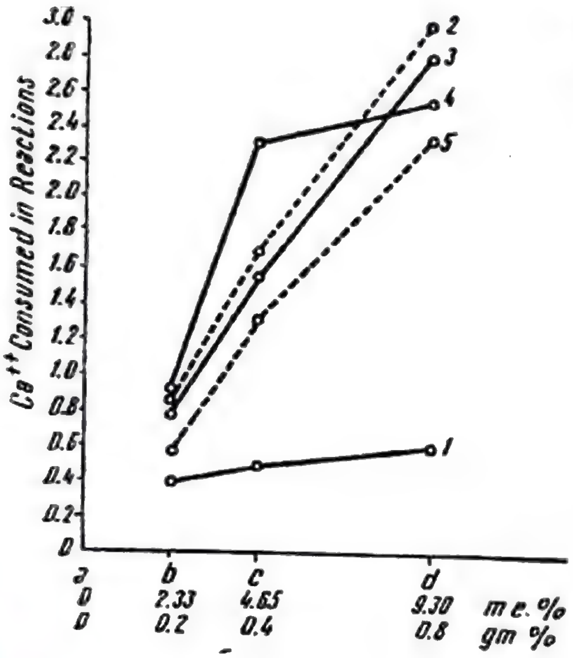


Fig. 9. Effect of Gypsum Treatment on the Calcium Consumed in Reactions in the Non-Alkali Soil Samples in Experiment 1(1 : 5).

Fig. 10. Effect of Gypsum Treatment on the Calcium Consumed in Reactions in the Alkali Soil Samples in Experiment 1(1 : 5).



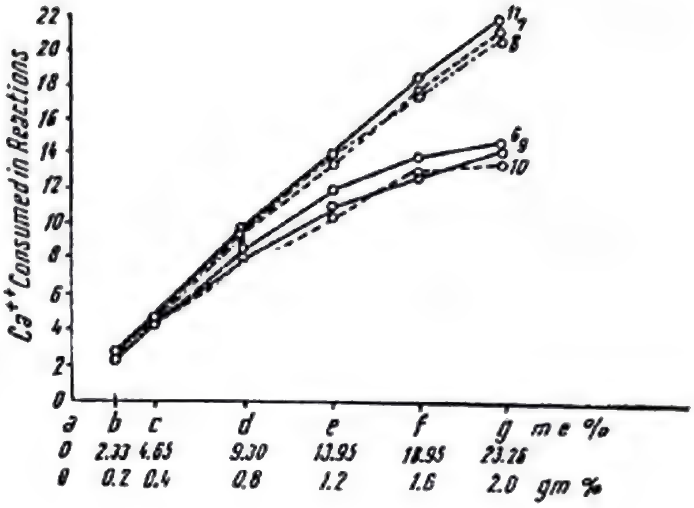
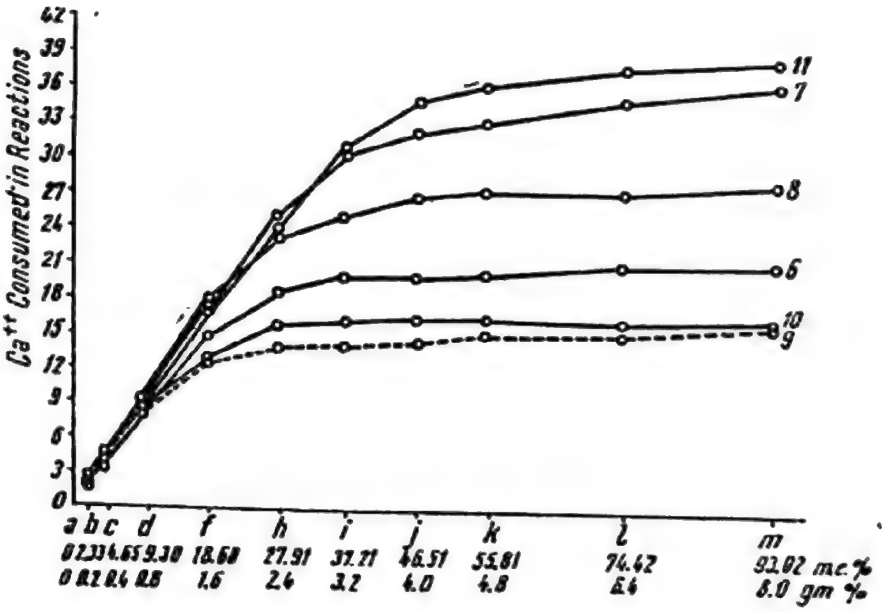


Fig. 11. Effect of Gypsum Treatment on the Calcium Consumed in the Reactions in the Non- Alkali Soil Samples in Experiment 2 (1 :20).

Fig. 12. Effect of Gypsum Treatment on the Calcium Consumed in Reactions in the Alkali Soil Samples in Experiment 2 (1 :20).



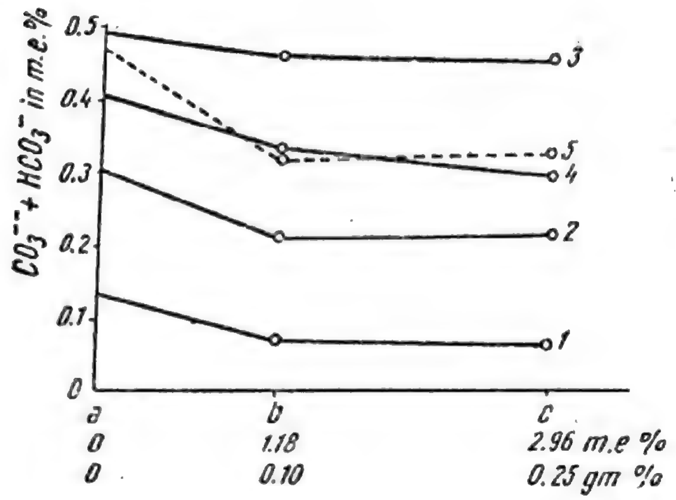


Fig. 13. Effect of Gypsum Treatment on Soluble Carbonate and Bicarbonate in the Non-Alkali Samples in Experiment 3 (Soil Paste).

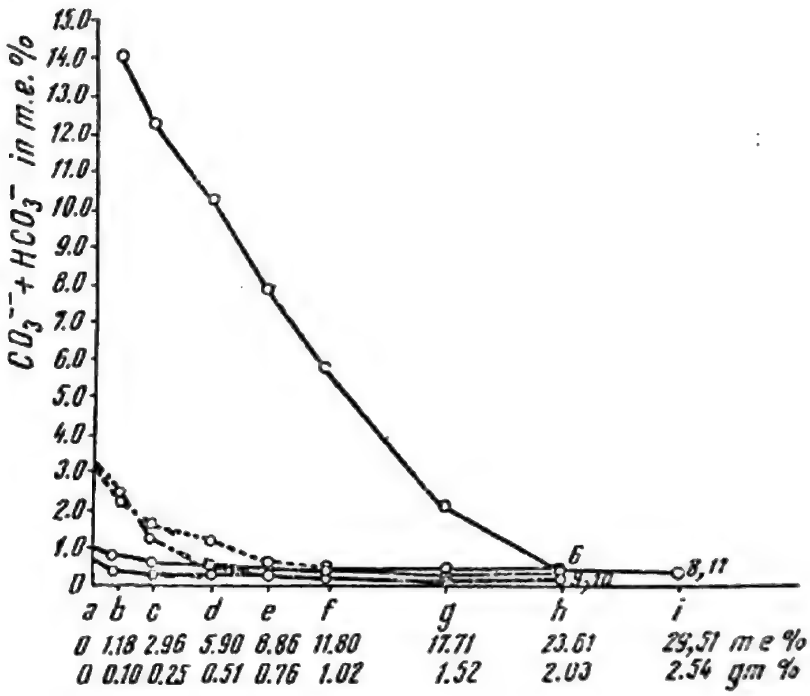


Fig. 14. Effect of Gypsum Treatment on Soluble Carbonate and Bicarbonate in the Alkali Soil Samples in Experiment 3 (Soil Paste).

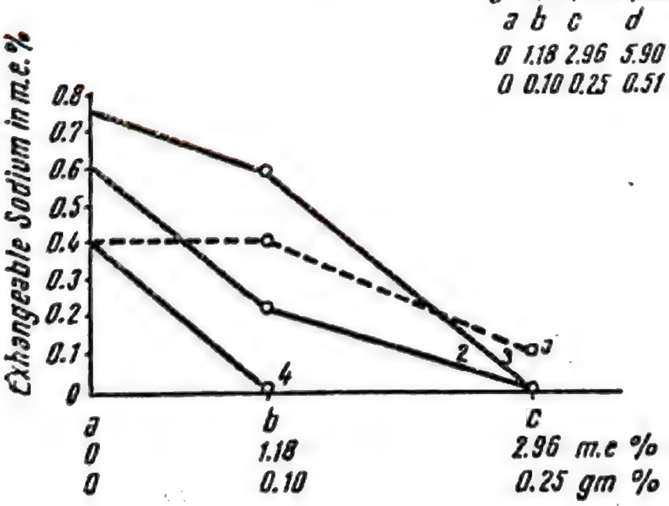


Fig. 15. Effect of Gypsum Treatment on Exchangeable Sodium in the Non-Alkali Soil Samples in Experiment 3 (Soil Paste).

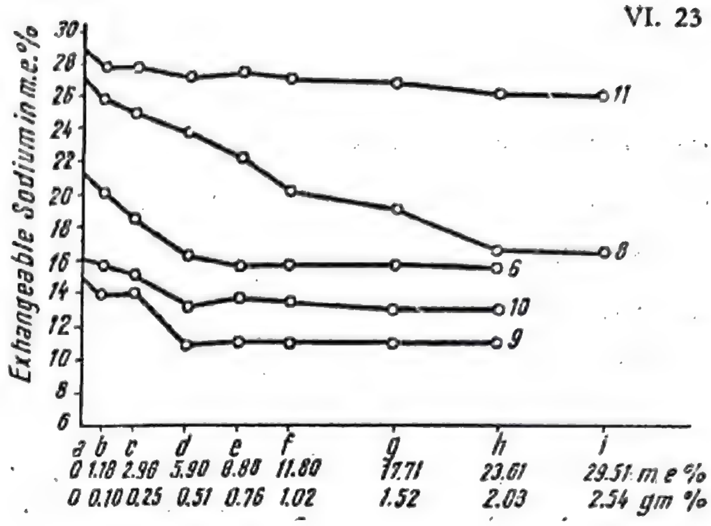


Fig. 16. Effect of Gypsum Treatment on Exchangeable Sodium in the Alkali Soil Samples in Experiment 3 (Soil Paste).

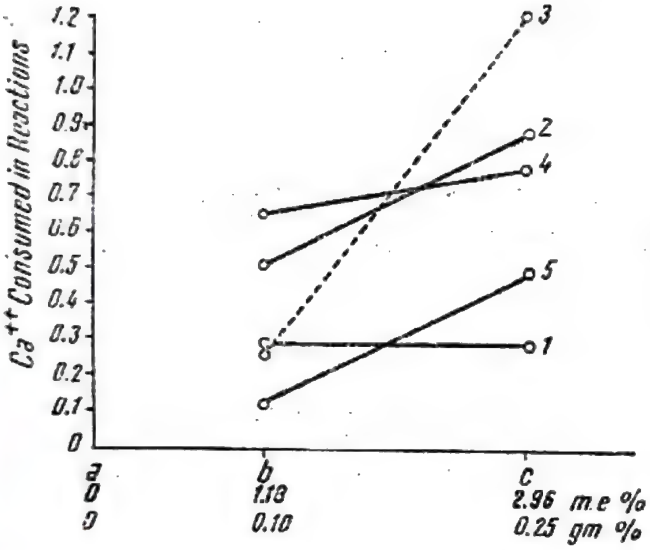


Fig. 17. Effect of Gypsum Treatment on the Calcium Consumed in Reactions in the Non-Alkali Soil Samples in Experiment 3 (Soil Paste).

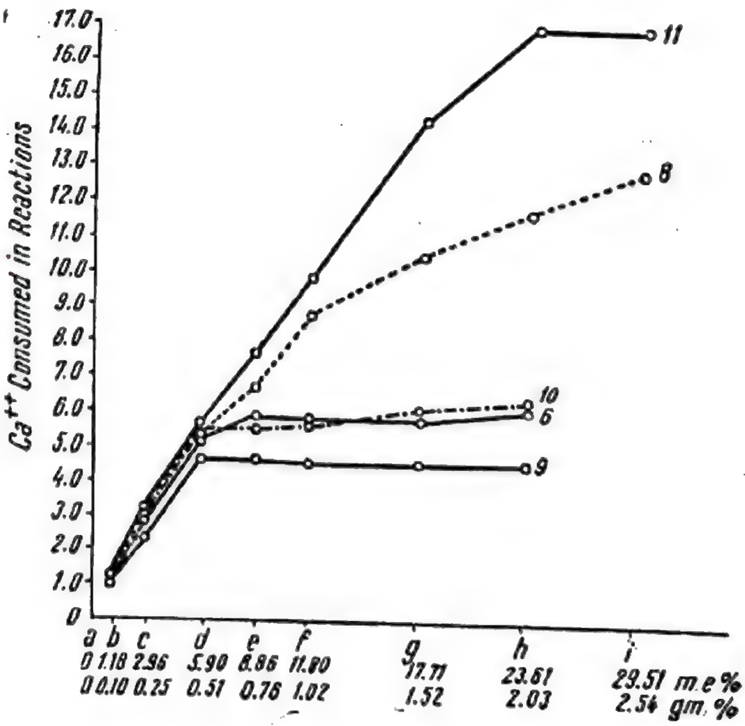


Fig. 18. Effect of Gypsum Treatment on the Calcium Consumed in Reactions in the Alkali Soil Samples in Experiment 3 (Soil Paste).

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SUMMARY

A laboratory study was made on the chemical changes which differents soils of Egypt sndergo by gypsum treatment under different soil: water ratios. Six alkali and five non-alkali uoil samples were examined. Three dilutions were tested namely, soil paste, 1 : 5 and 1 : 20, soil : water ratios.

RÉSUMÉ

On a étudié au laboratoire les modifications subies par différents sols d'Egypte à la suite des traitements au gypse à différents rapports sol-eau. Six échantillons de sols alcalins et cinq de sols non-alcalins ont été examinés. Dans les essais on a expérimenté trois dilutions : pâte de sol et rapports sol/eau de 1 : 5 et de 1 : 20.

ZUSAMMENFASSUNG

Es wurden Laboratoriumsversuche angestellt über die chemischen Veränderungen, die in verschiedenen Böden Ägyptens durch Gips-Behandlung bei verschiedenen Bodenwasserverhältnissen vorsichgehen. Es wurden sechs alkalische und fünf nichtalkalische Bodenproben untersucht. Dabei wurden drei Verdünnungen geprüft, und zwar : Bodenpaste, 1 : 5 und 1 : 20 Boden/Wasser-Verhältnisse.

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

IMPROVING OF ALKALI SOILS WITH SMALL DOSES OF RECLAMATION MATERIALS

L. ÁBRAHÁM[1], I. SZABOLCS[2]

The reclamation of alkali soils was based on the application of substances which entered into ion exchange with the alkali soil. It is well known that the unfavourable physical, chemical and biological properties of alkali soils are mainly due to the fact that the amount of exchangeable sodium ions is rather considerable compared to other cations. The reclaiming agents contain calcium and effect the substitution of Na ions by Ca ions.

Methods of applying various substances, usually gypsum, acid metal salts or industrial wastes, respectively, have been adopted during the last decades or even earlier. Besides, in Hungary, several substances containing calcium carbonate have been used to a great extent for alkali land reclamation.

The effectiveness of such materials is due to the fact that a group of Hungarian alkali soils have somewhat leached, slightly, acid surface horizons, and thus the calcium carbonate is more or less effective. Another method which is in use in Hungary is the application of the so-called "digo-earth", i.e. subsoil containing marl and some gypsum but only a low amount of salt, which is spread on the alkali surface and worked into the soil.

The above mentioned methods are right and efficient but they are rather expensive ones, thus only areas of limited extent could be improved this way. Moreover, the reclaiming material has sometimes to be shipped from far (several hundred miles). The amounts of substances to be worked into the soil are of orders of several million kg, the costs of hauling and shipping are in any case considerable. It has been pointed out in literature, relatively long ago, that the effect of calcium compounds applied in order to reclaim alkali soils cannot be fully attributed to simple ion exchange processes. In case of reclamation with Ca-containing substances, even in low amounts, certain changes in the calcium metabolism of plants take place and contribute to increase the yields.

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It was found on applying high amounts of calcium carbonate — 35, 40 or 50 tons, respectively, per hectare — that only a very low per cent of such doses became utilized, i.e. exerted some effect by way of ion exchange.

Based on these observations, experiments were conducted on alkali soils in Hungary with low amounts of reclaiming substances. These experiments were layed out on soils that would have been reclaimed in the past with large amounts (25, 30 or 40 tons/hectare) of the digo-earth mentioned or of calcium carbonate.

Table 1 contains some data on the chemical properties of the soils of the experiments.

Table 1

Some Chemical properties of the Experimental Soils

Site and depth of sample, cm		Total salt %	Exchangeable sodium per cent of total exchangeable cations	pH	Humus per cent
Kunszentmárton	0— 20	0.088	14.2	6.8	3.4
	80—100	0.540	—	7.9	—
Nagysziget	0— 20	0.154	9.0	7.2	2.6
	80—100	1.195	—	8.0	—
Besenyszög	0— 20	1.113	18.6	6.7	3.1
	60— 80	2.333	—	8.2	—
Karcag	0— 20	0.125	10.9	7.0	2.4
	60— 80	2,196	—	8.5	—
Pankota I	0— 15	0.170	9.16	7.3	4.7
	70— 80	0.460	—	8.3	—
Pankota II	0— 20	0.250	16.9	7.0	3.8
	60— 80	0. 80	—	7.8	—

It can be seen that the total salt content of these soils is rather high especially in deeper horizons. The alkali character of the soils becomes even more evident on computing the proportion of exchangeable Na ions in the surface horizons to total exchangeable cations (me per cent). The pH values, too, indicate alkali soils, notwithstanding the fact that in the Great Plain of Hungary the upper horizons of the soils are often slightly acid.

Formerly the conventional reclamation method was performed on these soils by appling Ca in amounts equivalent to the exchangeable sodium per cent. In the present experiments, only from 10 to 15 per cent of the calculated and conventionally used amounts were applied. The reclaiming substances were lime and gypsum, in some instances a mixtures of both.

In connection with the conventional method the application of manure has always been recommended and has been effective in most cases. In the present experiments, manure was only occasionally applied or substituted sometimes by fertilizers with comparable nutrient content. Some characteristic features of these experiments conducted for several years are presented in table 2.

Table 2

Yield Increases Obtained by Low Doses of Reclaiming Materials

Site	Crop	Dose	Yield increase per cent	L.S.D. 95 per cent
Kunszentmárton	Sugar beet	1060 kg/ha granulated	8.8	4.08
Nagysziget	Maize	554 kg/ha granulated	17.68	3.75
Besenyszög	Wheat	1060 kg/ha granulated	16.23	3.84
Karcag	Wheat	1060 kg/ha granulated	8.71	4.30
Pankota I	Vetch and oats	1800 kg/ha powder	26.7	8.5
	"	27000 kg/ha powder	21.2	8.5
Pankota II	Maize	2080 kg/ha granulated	20.1	18.7
Pankota II	Sugar beet	700 kg/ha granulated	11.8	5.2

It is evident that, in the cases mentioned, low amounts of reclaiming materials effected significant increases in the yield of grain and row crops as well. The same is true with respect to fodder crops. A part of the trials was conducted with parallel applications of the conventional high and low doses, respectively, of reclaiming substances. The results show that yield increases obtained with the low doses were not smaller, frequently even larger that those obtained with high amounts of the reclaiming substances.

In some experiments the reclaiming materials, applied in low doses, had been granulated previously. This proved to be advantageous, especially with row crops affording the incorporation of the amending material into the soil together with the seed. Thus more favourable circumstances arose around the germinating and growing plant, enhancing the development of it; the more developed plants endured the alkalinity of the soil better. In this manner by gradually invigorating the plants and improving the soil step by step, the roots of larger and better developed plants may themselves contribute materially to the reclamation of the soil.

As data show that, with respect to yield, nothing is gained through application of high versus low doses of reclaiming substances, the latter, on the contrary, often displaying more favourable effects, analyses were performed in order to ascertain the influence of high-dose and low-dose reclamation, respectively, on the chemical composition of plants. Some of the results are given in the following tables, data referring to sugar beets in No.3, and to vetches with oats in No. 4. According to data in table 3. the sugar content of beets is materially increased by the reclamation of the alkali soil, independently of the amount of reclaiming material applied. The raw protein content and parallel to it also the nitrogen content of vetches as well as of oats was similarly increased by reclamation, again independently of the amount of reclaiming material doses.

Table 3

Sugar Content of Beetroots on Reclaimed and Unreclaimed Soils, Respectively

Variant	Ash, per cent	Sugar content on the 70 per cent moisture basis
Check	1.47	14.57
1,060 kg/ha granulated reclaimed	1.93	18.71

Table 4

Chemical Analysis of Vetches and Oats Grown on Reclaimed and unreclaimed Soils, Respectively, on the Basis of 14 per cent Moisture in Hay

Variant	N per cent	Row protein per cent
Oats		
Control	0.98	6.12
1,800 kg/ha reclaiming material	1.05	6.56
27,000 kg/ha reclaiming material	1.11	6.93
Vetches		
Control	2.00	12.50
1,800 kg/ha reclaiming material	2.10	13.13
27,000 kg/ha reclaiming material	2.15	13.43

These findings fully confirm the results of the preliminary trials mentioned above, proving that the action of reclaiming materials is by no means restricted to ion exchanges taking place on the surface of colloids but it is much more complicated and calcium compounds, added to the soil even in low amounts, exert considerable influence on processes in plant physiology.

It must be pointed out, however, that reclamation with low amounts of materials cannot be accomplished in all cases. For exeample, if the soil contains much soluble salt amounting to 0.5 per cent in the surface layer, then neither low nor high amounts of amendments may be effective without previous salt leaching.

Neither is it advisable to apply low doses of amendments to alkali soils of the solonetz type where sodium amounts from 30 to 35 per cent of the total exchangeable cations and prevents plant production entirely.

Such soils and similar ones should become improved as natural pastures; low amounts of reclaiming materials may be very effective. It is most advisable to apply Ca nitrate because Ca in this form is quickly taken up by soil particles, and subsequently, soon reaches various plant organs. At the same time the other constituent of the compound, the nitrate, satisfies the need of plants for nitrogen which is rather considerable on such soils. This method of reclamation may be combined with irrigation. In the course of several years, a good pasture or even meadow may result, in some cases the soil becoming suited to ploughing. The experiences collected in Hungary on the improvement of alkali soils with low amounts of reclaiming materials may be of value elsewhere, especially in countries with moderate climate, where soil conditions are similar.

SUMMARY

The authors layed out several trials on alkali soils using but fractions — from 10 to 15 per cent—of the conventional doses of reclaiming materials. The majority of the experimental soils belonged to the solonetz type. The reclaiming material was sometimes applied in granulated form together with the seed, in other cases it was incorporated in the rows or spread on the surface of the soil. The crops of the experiments were cereals as well as row or fodder crops. The low doses of reclaiming materials significantly increased yields, by from 8 to 25 per cent, in all cases. The effect of low viz. high amounts of reclaiming materials were compared in some cases and it was found that low doses were as or even more effective than high ones. Plant analyses showed that reclamation with low doses considerably increassed the sugar content of beetroots and the protein content of fodder crops.

RÉSUMÉ

Les auteurs ont fait des essais sur des sols à alcalis avec de petites quantités de ce matériel, s'élevant à 10—15% de la dose usuelle. Les sols étaient du type solonetz. Dans certains cas ils ont employé le matériel d'amendement sous forme granulée, simultanément avec les semences, par ailleurs ils l'ont répendu en lignes ou sur la surface du sol. Ils ont fait ces essais avec plusieurs espèces de plants céréalières et des plantes sarclées ou fourragères; par l'emploi de petites quantités du matériel ils ont obtenu un accroissement significatif du rendement de 8 à 25%. Ils ont comparé les effets des petites et des grandes quantités employées constatant que l'effet de la petite dose égale et même surpasse l'effet de la grande dose. L'analyse chimique des plantes a montré que sous l'effet de l'amendement à petites doses, la teneur en sucre des betteraves avait appréciablement augmenté, ainsi que la teneur en protéines des plantes fourragères.

ZUSAMMENFASSUNG

Von den Verfassern wurden Versuche mit nur 10 bis 15% der üblichen Gaben von Meliorationsmitteln angelegt. Die Versuchsböden gehörten überwiegend dem Solonetztyp an. Das Meliorationsmaterial wurde in einigen Fällen gekörnt und zusammen mit dem Saatgut oder auf die Oberfläche des Alkalibodens eingebracht. Die Versuchspflanzen waren verschiedener Art, Getreide, Hackfrüchte oder Futterpflanzen. Kleine Gaben der Meliorationsmittel zeigten jedesmal gesicherte Mehrerträge von 8 bis 25%. Mehrmals wurde die Wirksamkeit geringer Gaben mit jener von hohen verglichen und es zeigte sich, dass die Ergebnisse mit den ersteren ebenso hoch oder höher waren als jene mit den grösseren Gaben.

Aus Analysen der Pflanzen ging hervor, dass bei Anwendung kleiner Gaben von Meliorationsmitteln sowohl der Zuckergehalt von Zuckerrüben als auch der Eiweissgehalt bei Futterpflanzen anstieg.

DISCUSSION

M. L. DEWAN (FAO) 1. In your view, what is in the reclamation material that is the reason for the improvement of alkali soils studied by you?

Is it due to

— quantity of Gypsum,
— amount of organic matter,
— modification of texture or structure,
— modification of exchangeable cations and anions,
— or a combination of above or some other causes.

2. Were your experiments done on non alkali soils to have a comparative study and an insight into the possible causes of improvement?

3. Although experiments are in preliminary stage, can you give any idea of the costs of your experiments, as compared to this improvement obtained.

I. SZABOLCS. 1. The influence of small doses of reclamation materials to soil depends on:

— Ion exchange,
— Changes of calcium metabolism in plants,
— Influence on physical, physicochemical and biological soil properties.

2. Slightly acid soils may also be reclaimed with application of small doses.

3. Cost depends on the concrete economical conditions and on the natural conditions.

W. H. VAN DER MOLEN (Netherlands) 1. How is the effect of small doses on soil structure? 2. Has the treatment to be repeated in order to have lasting effects?

I. SZABOLCS. 1. Probably changes exist in the structure after the amelioration both with small and high doses of reclamation materials, but regarding the errors of determination, it is difficult to determine them in all cases.

2. On solonetz soils strongly turning into steppe formation, application of small doses are enough only once, on solonetz soils turning into steppe formation, it is better to repeat this method after 3—4 years.

DIE WEITERENTWICKLUNG DER MELIORATION DER KARBONATFREIEN ALKALIBÖDEN (WIESEN-SOLONETZBÖDEN) DURCH UNTERGRUNDLOCKERUNG

I. PRETTENHOFFER[1]

Die Verbesserung der karbonatfreien Szikböden (in Versteppung begriffene Wiesen-Solonetzböden) mit Kalkung und Überschichtung mit kalkigen Unterböden und ihrer schwach alkalischen Varianten mit dem neuerdings ausgearbeiteten kombinierten (Kalk + Gips und Unterschichtung mit Schwarzerde) Verfahren ist in Ungarn in grossbetrieblichem Massstabe im Gange (I. Prettenhoffer, 1955; E. Prettenhoffer, 1955). Im gegenwärtigen 5-Jahres-Plan ist die Verbesserung von rund 35 000 kh in Aussicht genommen. Trotz der guten Erfolge dieser Meliorationsmethode strebte die Forschung eine weitere Entwicklung derselben an. Die an den verschiedenen Untertypen und Varianten der kalkfreien Alkaliböden durchgeführten chemischen Untersuchungen haben ergeben, dass der Prozess der Melioration — wenn auch langsam — zu den unteren, tieferen Schichten allmählich vordringt (I. Prettenhoffer, 1956). Sie weisen auch darauf hin, dass durch Förderung des Vordringens des Verbesserungsprozesses in die Tiefe, durch Lokkerung des Untergrundes, der Vorgang beschleunigt werden kann und so durch Vertiefung der fruchtbaren Krume der Alkaliböden, durch Verbesserung der Wasserverhältnisse und Begünstigung der Durchwurzelung die Erträge der verbesserten Szikböden noch weiter gesteigert werden können. Zur Auflockerung des Untergrundes konnte infolge der ungünstigen chemischen Zusammensetzung des Profils dieser Bodenart nur die Tiefbearbeitung ohne Umpflügen in Frage kommen. Nach den experimentellen Daten unserer diesbezüglichen Untergrundlockerungs-Modellversuche hatte die Auflockerung der unteren Schichten eine Verbesserung der Wasserhaushaltverhältnisse gebracht, wodurch die Salzakkumulationsschicht wesentlich tiefer zu liegen kam (I. Prettenhoffer, 1955; E. Prettenhoffer, 1955) und zwar mit Bodenverbesserung von 1,3% auf 0,2%, aber auch ohne Bodenverbesserung beträchtlich, nähmlich auf 0,5%, zurückgegangen war. Dieser grundlegende Versuch war wegweisend für die Weiterentwicklung der Meliorationsarbeiten durch Untergrundlockerung der kalkfreien Alkaliböden.

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Die Ergebnisse der an der Gruppe der besseren kalkfreien Szikböden, den *kalkfreien, nahezu neutralen Szikböden,* vier Jahre hindurch (1955—1959) mit dem deutschen einscharigen Untergrundlockerer „Cu 4" und anderen Untergrundlockerungspflügen durchgeführten zahlreichen Versuche zur Untergrundlockerung haben gezeigt, dass die Auflockerung der tieferen Schichten der Alkaliböden im allgemeinen die Ertragsergebnisse günstig beeinflusst haben. Die ertragssteigernde Wirkung der Untergrundlockerung schwankte — in Abhängigkeit von der Szikbodenvariante, den Versuchspflanzen, der Witterung und dem Jahre der Untergrundlockerung zwischen 0—28% (I. Prettenhoffer und Gratz, 1961). Sowohl die chemischen als auch die physikalischen Eigenschaften dieser Gruppe von Szikböden sind nicht so ungünstig, so dass infolgedessen auch die Wirkung der Untergrundlockerung auf die Ernteerträge keine so hochgradige ist, ja in gewissen Fällen sogar ausbleiben kann.

Bei der *kalkfreien, schwach alkalischen Gruppe* der Szikböden war — in Anbetracht der überaus ungünstigen chemischen und physikalischen Beschaffenheit des Unterbodens (hochgradiger Salzgehalt, ja oft sogar Sodagehalt, sehr kompakter *B*-Horizont) — durch die Untergrundlockerung sowohl infolge Verbesserung des Wasserhaushaltes, als auch durch Auswaschen der Salze und Förderung der Durchwurzelung ein weitaus grösserer Effekt zu erwarten. Bei dieser Szikbodengruppe ist in Dürre-Jahren ein nennenswerter Ertrag auch nach vorangegangener Bodenverbesserung nicht zu erreichen.

So hat sich bei diesen Alkaliböden die Verbesserung der Untergrundverhältnisse als ein Kernproblem erwiesen.

Die Versuche begannen 1957 an den kalkfreien, schwach alkalischen Szikböden mit unterschiedlicher Untergrundbeschaffenheit jenseits der Theiss mit Lockerungsgeräten, und zwar grossenteils an mittelgrossen und zum geringeren Teil an kleinen Parzellen (I. Prettenhoffer, 1960, 1963). Bei diesen Böden handelt es sich nach der genetischen Klassifizierung um sulfat- bzw. sulfat-karbonathaltige Wiesen-Solonetzböden bzw. deren krustige oder mittlere Varianten, bei denen der Versteppungsprozess schon eingesetzt hat. Gewöhnlich ist ihre Oberfläche bereits solodisiert (Szabolcs und Jassó, 1959). Wir haben 11 Untergrundlockerungsversuche angestellt, bei denen in der Mehrzahl die Lockerung mit deutschen einscharigen Untergrundlockerungsgeräten, mit einem Abstand der Scharen von 60—70 cm und in Tiefen von 30, 40 und 50 cm bzw. nur rund 50 cm, vorgenommen wurde. In zwei dieser Versuche erfolgte die Lockerung auf Kleinparzellen mit manueller Bearbeitung. In der Regel gingen wir so vor, dass — entsprechend der Alkalibodengruppe — die Melioration (Kalk + Gips) einheitlich vorgenommen wurde, nachdem zunächst die Auflockerung stattgefunden hatte. Ohne Bodenverbesserung ist nämlich auf diesen aussergewöhnlich schlechten Szikböden eine Vegetation kaum zu erhalten, wodurch die Auswertung erschwert wird. Die Lockerung des Untergrundes vor der Bodenverbesserung ist das zweckmässigste Verfahren. Wenn nämlich die Lockerung nach der Verbesserung stattfindet, so können wegen der starken Bindigkeit und der grossen Trockenheit des Untergrundes stark salz und so-

dahaltige Unterbodenschollen an die Oberfläche befördert werden, die die Struktur der verbesserten Krume beeinträchtigen.

Die Zusammenfassung der bei den 11 Freilandversuchen insgesamt 42mal ermittelten Ernteerträge zeigt, dass die Wirkung der Untergrundlockerung, je nach verschiedenen Pflanzen der Fruchtfolge, bei der maschinellen Lockerung der mittelgrossen Parzellen vorwiegend bis zu 50 cm Tiefe im Durchschnitt von 1—4 Jahren nach dem Eingriff 19,8% betrug (Tabelle 1). Bei den Kleinparzellen-Modellversuchen, wo die Lockerung eine optimale war, ergab sich eine wesentlich grössere Effektivität der Untergrundlockerung, nämlich 50% (I. Prettenhoffer, 1963). Bezüglich der Wirkung der verschieden tiefen Untergrundlockerung in den Versuchen an mittleren Parzellen, ergab sich im Durchschnitt der vier Jahre bei 30 cm Lockerung ein Erfolg von 6,8%, bei 40 cm von 15,9% und bei 50 cm von 27,8%, das heisst ein progressiver Anstieg mit zunehmender Tiefe. In den Kleinparzellen-Versuchen stieg die Wirkung bei Lockerungstiefen von 30—60 cm allmählich von 21,1 auf 76,8%. Während der vergangenen vier Versuchsjahre hat sich an diesen Alkalibodenvarianten die Untergrundlockerung als nachhaltig erwiesen.

Versuche an verbesserten und unverbesserten Szikböden haben gezeigt, dass die ertragssteigernde Wirkung der Untergrundlockerung im Laufe mehrerer Jahre und im Durchschnitt zahlreicher Versuche annähernd gleich ist. Für die mittelgrossen Parzellen ergeben sich Werte von 29,1 und 25,2 und für die kleinen Parzellen von 26,7 und 26,2 %. Es kam vor, dass in den einzelnen Versuchen in Jahren mit günstiger Witterung auf den meliorierten Szikböden — ausser der augenfälligen Wirkung der Bodenverbesserung — ein weiterer ertragssteigernder Effekt der Untergrundlockerung nicht zu verzeichnen war, gleichzeitig aber auch, dass bei unverbesserten Szikböden — insbesondere bei den schlechtesten Varianten — die Wirkung der Untergrundlockerung in Ermangelung eines befriedigenden Pflanzenbestandes, ausblieb. Da aber bei diesen Alkaliböden als Tiefenbearbeitung einzig und allein die Untergrundlockerung in Frage kommt, unterstützt dies die Existenzberechtigung der Untergrundlockerung auch im Falle der unverbesserten Szikböden. Die Wirkung der Untergrundlockerung auf den Ertrag der einzelnen Pflanzenarten kommt der gleich, wie sie in Versuchen auf freien, nahezu neutralen Böden beobachtet wurde (I. Prettenhoffer, 1960). Am niedrigsten ist sie bei den Getreidearten (20,9%), höher bei den Grünfutterpflanzen (25,5%) und am höchsten bei den Hackfrüchten (44,0%).

Die erörterten Versuchsergebnisse zeigen, dass bei dieser schlechtesten Variante der kalkfreien Alkaliböden die Untergrundlockerung von wesentlich grösserer und nachhaltigerer Wirkung ist als bei den annähernd neutralen Böden. So kann die Untergrundlockerung, die bei den letzteren als eine ergänzende Massnahme der Sodabodenverbesserung gelten kann, bei den schwach alkalischen Szikböden als ein der Bodenverbesserung fast gleichwertiges und parallel dazu anwendbares Verfahren betrachtet werden.

An einem grossen Teil der Bodenprofile unserer Versuchsparzellen haben wir zur Emittlung der sich in ihnen unter dem Einfluss der Untergrundlockerung abspielenden Veränderungen an Fixpunkten zu Versuchs-

Tabelle 1

Wirkung der in verschiedenen Tiefen durchgeführten Untergrundlockerungen in Prozenten, während 1—4 Jahren

***A* Bei Versuchen mit mittelgrossen Parzellen**

Jahr der Wirkung der Untergrundlockerung	Pflügen ohne Steuerplatte 30 cm	Tiefe der Untergrund-lockerung, in cm			Mittelwerte der Unter-grundlocke-rungen von 30—50 cm
		30	40	50	
1-jährige Wirkung	Ø(1) (1)	Ø(1) (1)	24,0 (3)	31,9 (13)	18,6
2-jährige Wirkung	Ø (1)	10,5 (2)	10,0 (8)	24,5 (28)	15,0
3-jährige Wirkung	Ø (1)	10,0 (1)	30,0 (2)	23,6 (15)	21,2
4-jährige Wirkung	—	—	14,0 (1)	35,0 (9)	24,5
Mittelwerte der 1—4 jährigen Wirkungen	0	6,8	19,5	28,7	19,8
5-jährige Wirkung	—	—	—	9,0	9,0

***B* Kleinparzellen-Versuche**

Jahr der Wirkung der Untergrundlockerung	Tiefe der Untergrundlockerung in cm				Mittelwerte der Unter-grundlocke-rungen von 30—60 cm
	30	40	50	60	
1-jährige Wirkung, Zuckerrüben	60,5	115,5	168,0	241,0	146,2
2-jährige Wirkung, Winterweizen	16,0	23,7	36,0	18,2	23,4
„	42,0	60,5	87,5	104,0	73,5
3-jährige Wirkung, Steinklee	0	3,0	3,0	38,5	11,1
Zuckerrüben	14,5	44,5	58,0	59,5	44,0
4-jährige Wirkung, Steinklee	0	11,5	11,5	0	5,7
Mittelwerte de 1—4 jährigen Wirkungen	22,1	43,1	60,6	76,8	50,6

Die in Klammern befindlichen Ziffern geben die Zahl der durchgeführten Versuche an.

beginn und 2—4 Jahre darauf Proben entnommen und diese auf ihren Salzgehalt untersucht (I. Prettenhoffer, 1963). Dabei stellte sich heraus, dass an jenen Varianten der kalklosen, schwach alkalischen Szikböden, wo der Untergrund stark salzig (neutral salzig) ist — wie wir es auch in früheren

Untersuchungen beweisen konnten —, die der Bearbeitung unterzogen wurden, bereits auch durch die systematische Kultivierung an sich eine kontinuierliche Salzauslaugung festzustellen ist. So war z.B. im Versuch Nr. 14 — bei Kelemenzug — ohne Untergrundlockerung eine Salzauslaugung bis zu 40 cm, nach der Untergrundlockerung aber eine solche bis zu 60 cm Tiefe in den Profilen zu verzeichnen (Abb. 1). Mit gleichzeitiger Melioration werden nahezu ähnliche Ergebnisse erzielt. Die Bodenverbesserung hatte ausser der infolge des Kationenaustausches eingetretenen Auslaugung des Salzüberschusses — gegenüber den verbesserten, untergrundgelockerten Äckern — eine weitaus grössere Salzauslaugung veranlasst. Bei denjenigen kalkfreien, schwach alkalischen Szikböden, wo der nahe Untergrund sodahaltig, und daneben noch etwas neutral-salzig ist, war eine nennenswerte Salzelimination bisher nicht zu verzeichnen. Es wurde eher nur der im Anschluss an die Bodenverbesserung eingetretene Salzüberschuss nach 3—5 Jahren auf das ursprüngliche Niveau herabgesetzt.

Die durchgeführten Untersuchungen haben somit gezeigt, dass als Wirkung der Untergrundlockerung, in den Profilen der im Untergrund stark salzigen, kalkfreien Alkaliböden, radikale, günstige Veränderungen eingesetzt haben. Bei der infolge der Untergrundlockerung zustandegekommenen hochgradigen und anhaltenden Ertragssteigerung, spielen die durch die Salzauswaschung im Profil hervorgerufenen chemischen Veränderungen unbedingt eine Rolle. In den Modellversuchen deutet die gegenüber der mechanischen Lockerung zu beobachtende hochgradige Auswaschung darauf hin, dass bei der Untergrundlockerung eine möglichst gründliche Auflockerung angestrebt werden muss.

Schon die Beobachtung der Untergrundlockerungsversuche liess im 1. Jahr erkennen, dass die Arbeit des Untergrundlockerens mit einem Pflugkörper nicht ökonomisch ist, auch seine Auflockerungsleistung befriedigt nicht und bedarf der Vervollkommnung. Ich habe daher zur Anfertigung von Lockerungsmaschinen geraten, die für solche schwer zu bearbeitende Szikböden bemessen sind, und deren hängende Messer sowohl in ihrem Abstand voneinander als auch in ihrem Tiefgang regulierbar sind. Die Spezialisten der Bodenverbesserungs-Unternehmen haben diese Einrichtung in einer am Traktor Sz. 100 aufmontierbaren Form konstruiert und fertiggestellt. Bei den bisherigen Untergrundlockerungsarbeiten — gewöhnlich an Alkaliböden — hat sich diese bei Lockerungen in 40—50 cm Tiefe mit drei Scharen gut bewährt. Eine noch tiefere Lockerung ist — nach unseren bisherigen experimentellen Beobachtungen — gar nicht nötig. Gegenüber der Lockerung mit einscharigen Pflügen wird der Arbeitsgang mit dem dreikörperigen Gerät nicht unterbrochen, sondern kontinuierlich fortgesetzt und dabei eine Leistung von rund 1 kh/1,5 h erreicht. Die Kosten der Untergrundlockerung betragen für das Unternehmen ebenfalls ungefähr 300.-Ft/kh. Von diesen Untergrundlockerern wird — in Anbetracht der zusammenhängenden und intensiveren Lockerung und infolge der zustandekommenden günstigen chemischen und physikalischen Veränderungen — eine grössere Ertragssteigerung zu erwarten sein.

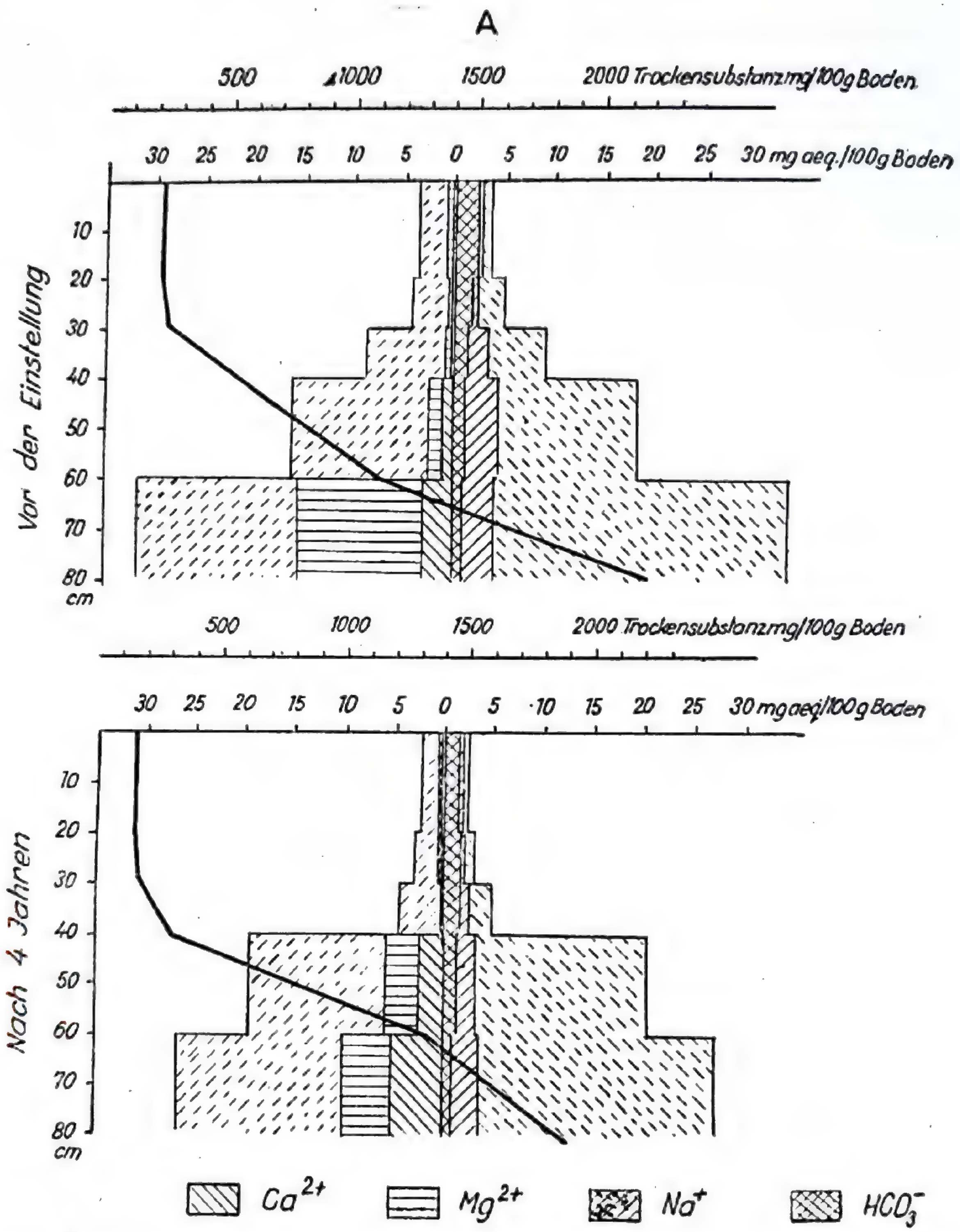

Abb. 1. Wasserauszugswerte der Profile, der in verschiedenen Tiefen bearbeiteten Parzellen, bei Kelemenzug (Versuch Nr. 14). Karbonatfreie, schwach alkalische Solonetzböden, Untergrund neutral salzhaltig: *A* — Grundpflügen (20 cm) ohne Verbesserung;

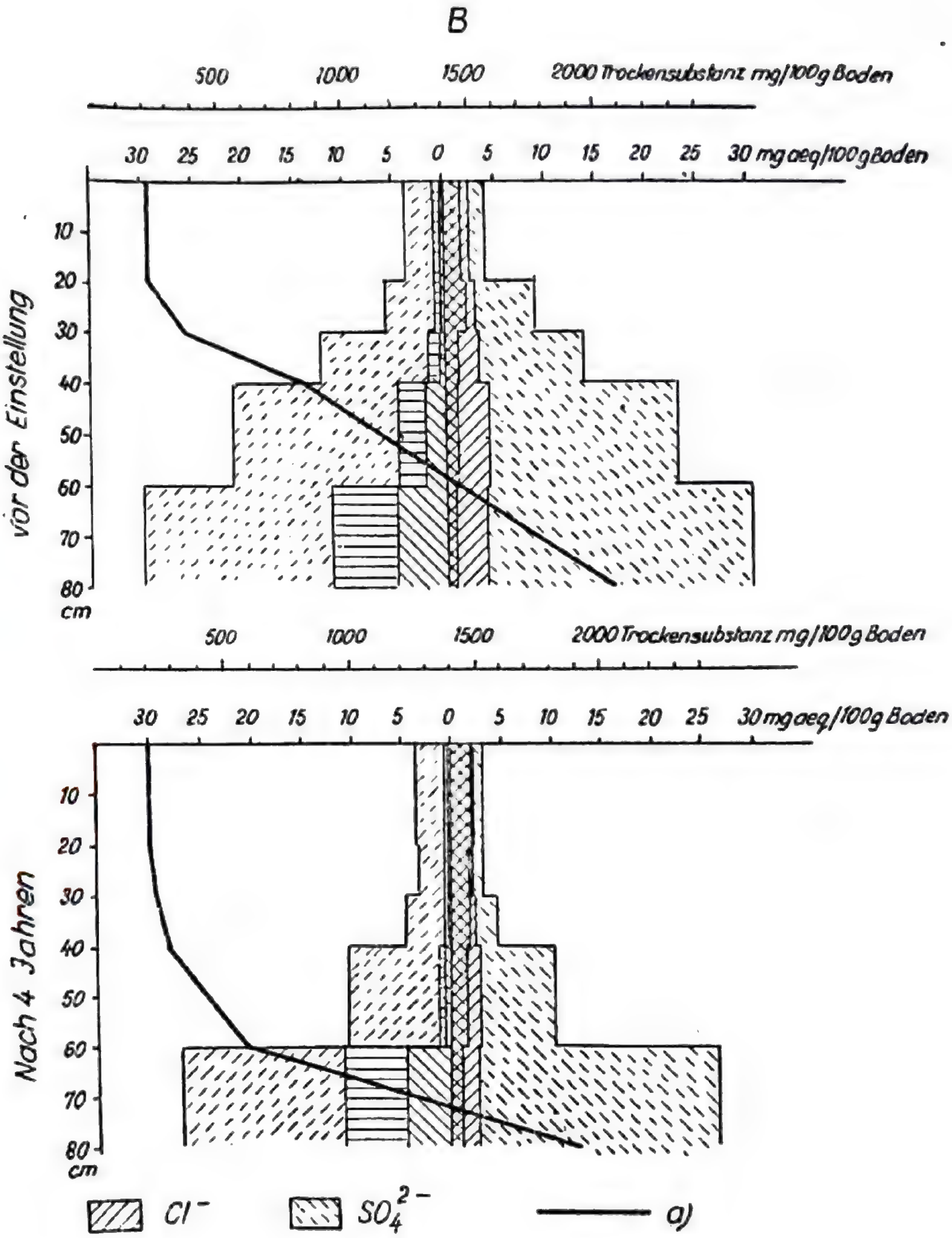

Abb. 1.
B — Untergrundlockerung (50 cm) ohne Verbesserung. Obere Abbildungen vor der Einstellung, untere nach 4 Jahren; *a* — Trockensubstanz in mg/100 g Boden.

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ZUSAMMENFASSUNG

Die Verbesserung der karbonatfreien Szikböden (Steppencharakter annehmende, sulfat- bzw. sulfat-karbonathaltige Wiesen-Solonetzböden) durch Kalkung und Überschichtung mit kalkhaltigem Unterboden, wird in Ungarn in grossbetrieblichem Massstabe durchgeführt. Eine Reihe von Untergrundlockerungsdauerversuchen wurden während 4 Jahren auf mittelgrossen und kleinen Parzellen durchgeführt (Modellversuche). Auf den mittelgrossen Parzellen wurde die Untergrundlockerung maschinell mit dem deutschen Gerät Cu 4 vorgenommen, während die kleinen Parzellen durch Handarbeit gelockert wurden. Die Tiefe der Untergrundlockerung betrug 30, 40 und meistens 50 cm, auf den kleinen Parzellen 60 cm. Im Laufe von 1—4 Jahren wurden im Durchschnitt der 42 mal ermittelten Ernteerträge der 11 Versuche auf mittelgrossen Parzellen, Ertragsanstiege von 19,8% und auf kleinen Parzellen solche von 50,6% erzielt; die Wirkung der Untergrundlockerung war dauerhaft.

Die besten Ergebnisse wurden bei Hackfrüchten (44,3%) erzielt; es folgen Futterpflanzen (25,5%) und Getreidearten (20,9%).

Zahlreiche Analysen der Salzzirkulation in den Profilen der Versuchsparzellen zeigten, dass in den Varianten mit stark salzhaltigem (neutralem) Untergrund, auf Grund der Unterbodenlockerung eine Salzauslaugung auftritt, die nicht nur in den Modellversuchen sondern auch auf den maschinell bearbeiteten Parzellen nennenswert ist.

Auf Anraten des Verfassers ist ein mehrschariger Untergrundlockerer konstruiert worden, der dem grossen Widerstand der Alkaliböden bemessen ist und dessen Anwendung eine grössere Ertragssteigerung erwarten lässt.

SUMMARY

Amelioration of noncarbonatic alkali ("szik") soils (sulphatic and sulphate-carbonatic meadow solonetz on the way towards steppification) by liming and by covering with calcareous subsoil is being practiced on large-farming scale in Hungary.

A number of continuous subsoiling experiments were conducted for 4 years on medium sized plots, also on small plots (model experiments). On the medium sized plots the subsoiling was mechanised, the Cu 4. brand single-bladed German subsoilcultivator being used; on the small plots it was made by manual labour. The depth of subsoiling was 30, 40 in, the majority 50 cm and, on small plots 60 cm. The yield increase owing to subsoiling, obtained in 11 experiments in the average of 42 weightings within 1 to 4 years, was 19.8 per cent in the experi-

ments on medium size plots and 50.6 per cent in the model experiments on small plots. During the years of our experiments the effect of subsoiling proved to be lasting.

The best results obtained were those with root crops (44.3 per cent) next came the fodder plants (20.5 per cent) and cereals were the last (20.9 per cent).

Numerous analyses concerning the circulation of salts in the profiles of the experimental plots have shown that on soil variants with strongly saline (neutral) subsoil the leaching down of salts owing to subsoiling was appreciable not only in the model experiments but also in the medium size plots subsoiled mechanically.

At the author's suggestion a subsoil cultivator (subsoiler) with several working pieces (blaodes) able to cope with the hard resistance of alkali soils was constructed, so that a greater increase of yields may be expected from its use.

RÉSUMÉ

L'amélioration des sols non-calcaires „szik" (solonetz sulfatique et sulfato-carbonaté de prairie en voie de transformation en sol de steppe) par chaulage et couvrage avec du sous-sol calcaire est pratiquée sur une large échelle en Hongrie. Les expériences ont été effectuées pendant 4 ans sur des parcelles de grandeur moyenne avec fouilleuse à couteau (marque Cu 4 de fabrication allemande) et sur les parcelles modèle avec labour manuel. La profondeur de l'ameublissement a été de 30, 40, et surtout 50 cm, sur les parcelles modèle de 60 cm. L'effet du sous-solage après 1—4 années d'amélioration était en moyenne de 19,8%, en tenant compte des rendements sur les parcelles de grandeur moyenne dans 11 essais en 42 cas. Dans les parcelles modèle l'effet est plus grand, 50,6%. Pendant 4 années d'expériences de sous-solage sur les types de sols alcalis l'effet a été permanent. Parmi les différentes cultures, les cultures sarclées présentent le plus grand rendement (44%), ensuite viennent les fourrages (25,5%) et enfin les blés (20,9%).

Les analyses de la dynamique des sels dans les profils d'essai montrent que sous l'action du sous-solage non seulement manuel, mais aussi mécanique, le lessivage des sels est considérable. Sur la proposition de l'auteur, la fabrication de fouilleuses à plusieurs couteaux pour les sols à alcalis a été perfectionnée et on peut s'attendre à des rendements accrus.

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SOLONETZ MELIORATION METHODS IN DIFFERENT ZONES OF THE U.S.S.R.

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Solonetzes represent over 100,000,000 ha of the vast Soviet steppes. According to the nature of salinity, the solonetzes fall into two categories:

1) soda-sulphate (alkali) solonetzes of meadow and meadow-steppe type of the chernozem zone;

2) chloride-sulphate and sulphate-chloride (neutral) solonetzes of the zone of chestnut soils.

1) *Soda-sulphate solonetzes* chiefly occur in the forest-steppes of Western Siberia, the Ukraine, the Central chernozem regions as well as in those of inter- and sub-montane regions with rising ground waters, e.g. in the Chu River Valley of Kirghizia, Araka River Lowland of Armenia, etc.

The total area under soda-sulphate solonetzes and solonetzic soils in the U.S.S.R. comprises some 9,000,000 ha.

The soda-sulphate solonetzes of meadow, meadow-steppe types and of various subtypes occur outside the U.S.S.R., viz., in Hungary (among the meadow and meadow-steppe chernozems, between the Danube and Tissa and Tissa and in the Trans-Tissa region), in Rumania, Yugoslavia, Czechoslovakia, Bulgaria, Egypt (the Nile Valley), Ghana, Northern and Werstern China, India and Pakistan, Iran, and in the Western United States (California, Arizona, New Mexico, Oregon, Colorado, etc.).

The profound theoretical analysis of the genesis and reclamation of solonetzes put forward by Gedroits (1912—1928) was fundamental for their large-scale reclamation.

Almost simultaneously with Gedroits, the sodium-exchange theory of solonetz genesis was expounded by such eminent researchers as Zigmond (1916), Hissink (1922) and Kelley (1924—1951).

Since soda-sulphate solonetzes occur among meadow and meadow-steppe chernozems, i.e., in the most intensively cropped areas, it is the solonetzes of this zone that attracted most the soil and reclamation experts both at home and abroad.

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The solonetzes of the chernozem zone depend for their reclamation first and foremost, on chemical methods.

Application of powdered gypsum is the most advanced and practical of the chemical methods. Gypsum rates for application are determined in each particular case by the exchangeable-sodium equivalent in the A and B solonetz horizons of the improved soil minus 5 me (10 per cent) of exchangeable sodium as against the total base-exchange capacity. In the U.S.S.R., large-scale soil improvement has now been going on for 30 to 35 years. A prolonged study has been made in the Ukraine of the solonetzes of the chernozem zone with a view to improvement by gypsum-application. According to the field tests conducted in the Ukraine and the Trans-Urals, the gypsum application to meadow solonetzes results in steady and bumper crops.

Gypsum application is made much more efficient by simultaneous additions of farm manure and mineral fertilizers. Thus in the tests of Mozheyko, the yield of grain crops went up thrice on crustal solonetzes, 1.6 times on deep solonetzes, and almost 1.5 times on solonetzic chernozems, the average of 17-year yield being 20 to 20.9 cwt per ha.

Such good crops on improved soda-solonchak solonetzes were obtained due to the radically altered salt regime and physico-chemical properties of the solonetzes. Gypsum application sharply decreases the alkalinity of solonetzes and the amount of water-soluble and exchangeable sodium which, in turn, leads to a considerable improvement in the moisture physical properties of these soils.

Soda solonetzes are greatly improved by seeding reclaimer crops such as sweetclover in the forest steppes of the Ukraine (Sambur), the Trans-Urals (Oborin), and of Western Siberia (N. D. Gradoboev et al.).

On soda-sulphate solonetzes in the Ukraine (Sambur), the Trans-Urals (Oborin), etc., after gypsum application such crops as sugar beet and maize proved especially successful.

The gypsum application of solonetzes is paid off before very long. Besides gypsum, gypsum-enriched clays widely occur in the Soviet Union containing 5—6 to 60—90% of gypsum, e.g. deposits in the Rostov Region, Azerbaijan, and Georgia.

If high enough in gypsum, these clays are good reclaimers of solonetzes. Thus, the application of clay-gypsum on the solonetzes of the Rostov Region resulted in a 15—21 per cent increase in wheat crops and highly increased cotton crops in Transcaucasia, etc.

Intensive research is now underway in the U.S.S.R. both in the laboratory and in situ aimed at the utilisation of industrial wastes in general and chemical-production wastes in particular for reclamation purposes.

The wastes of soda production, such as calcium chloride, are the most valuable chemical wastes.

Certain applications of chemical wastes are considered below.

a) The experimental development of solonetzes with calcium chloride (Antipov-Karataev and Pak on the Ergeni Upland and Caspian Lowland

and Mozheyko in the Ukraine) show $CaCl_2$ to be a highly effective reclaimer. At the same time, its use was limited to a sufficiently moistened soil in which the products of its reaction with soil were fully leached.

b) Iron vitriol is a waste of varnish pigment preparation which contains up to 53 per cent iron sulphate.

Oborin (Trans-Urals) showed that the application of iron sulphate sharply improved the moisture-physical properties, decreased the alkalinity of solonetzes and thus increased wheat crops. The application of 6 tons of iron sulphate (chemical waste) per ha on medium-columnar solonetzes resulted in a double wheat yield as against the control of 7.7 cwt per ha.

c) The industrial by-products used for solonetz reclamation include phosphorgypsum containing up to 70—75 per cent of gypsum and 2—3 per cent of P_2O_3.

d) Sulphuric acid rejected in rubber production can be applied for increasing cotton crops and for taking solonetzes under orchards and vineyards, according to the data collected on soda-sulphate solonetzes — solonchaks near Mount Ararat (Armenia). The application of 80%-sulphuric acid in an amount of 30 tons per ha of solonetz gives an increase in yields which is paid off in two years.

The reclamation effect of sulphuric acid goes up when it is applied selectively in layers and in combination with deep reclamation-tillage.

e) The application of sugar-production wastes mixed with oxidised coal (high in humic acids) is very good while increasing the yields of sugar-beet and tomato, according to a series of tests conducted on the soda-sulphate solonetzous serozems of the Chu River Valley (Kirghizia).

Apart from the application of chemicals, good results are obtained by "hauling in soil", i.e., covering the solonetz patches of the humus layer with chernozem from the adjacent plots using buldozers and scrapers. The experimental hauling in soil of chernozem solonetzes in the Kamennaya Step (Voronetz Region) which was conducted by Antipov-Karataev and al., proved most effective in raising the yields of crops.

While improving meadows and pastures on solonetzes and saline soils, good results were obtained by reclamative tillage, such as chiselling in combination with seeding solonetz- and salt-resistant plants.

In Western Siberia, the solonetz reclaimer plant was sweetclover, which promoted bumper yields of hay already in the first years of development. The yields of natural hay grasses do not normally exceed 3—5 double cwt per ha. At the same time, on those solonetz-solonchaks which are improved by appropriate tillage and sweetclover seeding, it is possible to raise the yields of these grasses 4—5 times Gradoboev and al.).

West-Siberian solonetzes were sown with sweetclover. As a result, the yields of its hay at times reached 50—60 double cwt per ha. Besides sweetclover, high yields were obtained on West Siberian meadow solonetzes and solonchaks of the following crops: awnless brome grass, hybrid lucerne, and certain local species. Sweetclover also grows well on the improved solonetzes of the Ukraine.

Therefore white and yellow sweetclover should make an indispensable reclaimer crop for the soda-sulphate solonetzes of meadow and meadow-steppe type.

2. *Chloride sulphate and sulphate-chloride solonetzes and solonetzic soils* occupy 90,000,000 ha of the total Soviet area under solonetzes. They chiefly occur in the steppes and arid steppes of Kazakhstan, the Volga region, and the south Ukraine including the Crimea. Now that animal husbandry has become a matter of primary concern on the newly developed virgin and fallow lands, the large-scale improvement of arid-steppe and semi-desert solonetzes and solonetz soils must also come to the fore.

The steppe, meadow-steppe, chloride-sulphate, and sulphate-chloride solonetzes of the chestnut and brown soil zones have a neutral or slightly alkaline reaction, often containing from a depth of 30—40 cm downwards much of calcium salts, e.g. lime or gypsum carbonates. Thus, the solonetzes of the chestnut and brown soil zones, which are rather vast, are reclaimed by use of the calcium resources of the soils themselves (either of soil gypsum together with calcium carbonate or of soil carbonates alone).

Therefore, agrotechnical practices are the most important in these zones including tillage and reclaimer-crop seeding which improves moisture storage and activities biological processes.

The Soviet soil and reclamation experts have done much in the late 30 years in the field of reclamation agrobiology, which includes a whole series of measures designed to raise the fertility of chestnut-zone solonetzes and thus to ensure bumper crops.

Among other things, the agrobiological method involves a system of deep tillage which brings about sweeping changes in the water-physical, physico-chemical and biological properties of soils, viz., a thick arable layer is created as a result of breaking up the compacted columnar horizon; the moisture-physical properties of the soil are improved and hence the moisture content is increased; the newly-formed thick arable layer takes up such soil-generated salts as lime carbonate and gypsum which not only improves the moisture regime of chiselled solonetzes but also accelerates the physico-chemical dealkalisation of the profile ;the resultant intensive development of plants and their roots in a relatively greater volume of soil, in turn, promotes the action of reclaimer crops.

The improved physico-chemical properties, moisture-air and nutrition regimes of solonetz soils resulting from the deep reclamation tillage makes for higher yields of crops.

The selection of reclaimer crops for solonetzes is essential for their reclamation as a whole.

On lands under irrigation, the following reclaimer crops are recommended: lucerne (synehybrid) which is highly resistant to salinisation and alkalisation and yields as much hay as 200 cwt per ha.

On non-irrigated steppe-columnar solonetzes,Agropyron sp. are highly resistant to droughts, salinisation,and alkalisation which also applies to sweetclover, Sudan grass, sorghum, black-eyed Susan, etc. The whole cycle of solonetz reclamation which includes chiselling and reclaimer-crop seeding

takes 3—4 years on lands under irrigation and 5—7 years on non-irrigated lands.

After cropping lucerne and chiselling for 3—4 years in conditions of irrigation, the soil is good enough to be taken under any crops and to produce high yields.

All the expenditure on reclamation is returned in 1—2 years because of the increase in yield.

As shown earlier in the paper, solonetzes in the U.S.S.R. are reclaimed by different methods from zone to zone.

For the soda solonetzes of meadow-steppe zones, chemical methods are preferred (gypsum application and treatment with industrial wastes), while for the chloride-sulphate (neutral) solonetzes of steppe zones use is made of the agrobiological reclamative complex.

The data collected by the Soviet soil researches and reclamation experts should be very helpful in developing vast lands under solonetzes both to be taken under crop and pasture.

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SUMMARY

Various solonetz melioration methods in different zones of this country are discussed. Solonetzlike soils in U.S.S.R. cover about 100 millions of hectars, of which about 10% of the chernozem zone with a soda salinization. About 90% of solonetz and solonetzlike soils with a Cl-SO_3 and SO_3-Cl type of salinization are situated in the chestnut and brown zones. Soda (alkaline) solonetzs are meliorated mostly by chemical substances — gypsum, $CaCl_2$ and different by-products of chemical industry ($Fe_2(SO_4)_3$; H_2SO_4 etc.) Long-term field experiments in the Ukraine and Transurals with gypsum application to meadow solonetz showed a 1.5—2.0 times increase in crop yields as to control. Solonetz of Cl-SO_4 and SO_4-Cl salinization are meliorated by a complex of agricultural measures (agrobiological method) that include meliorative tillage, water conservation, activition of biological processes, meliorative cropping. As meliorative crops on irrigated steppe solonetz, lucerne is recommended and without irrigation-Melilotus- Rudbeckia horta, Sorghum etc. Under irrigation, melioration of solonetz takes 3—4 years and under dry farming 5—7 years. The possibility of high yields of many agricultural crops (wheat, corn, sugar beet, chick pea, rice, sesame, Chinese bellflower etc.) on meliorated solonetz under irrigation, is ascertained. Expenses are paid off in 1—2 years.

RÉSUMÉ

On discute différentes méthodes d'amélioration des solonetz, appliquées dans diverses zones du pays. En U.R.S.S., les sols solonetzoïdes couvrent environ 100 millions d'hectares, dont quelque 10% dans la zone du chernozem avec salinisation du type carbonate de soude. À peu près 90% des solonetz et des sols solonetzoides avec salinisation du type Cl-SO_4 et SO_4-Cl sont situés dans les zones des sols châtains et bruns. Les solonetz (alcalins) à carbonate de soude sont surtout améliorés par des substances chimiques — gypse, $CaCl_2$ et divers sous-produits de l'industrie chimique : $Fe_2(SO_4)_3$; H_2SO_4 etc. Les expériences au champ à long terme effectuées en Ukraïne et dans le Transoural avec application de gypse aux solonetz de paririe alluviale ont fait voir une augmentation de 1,5— à 2,0 fois par rapport au témoin.

Les solonetz à salinisation du type Cl-SO_4 et SO_4-Cl sont améliorés par un complexe de mesures agrotechniques (méthode agrobiologique) comprenant les travaux amélioratifs du sol, la conservation de l'eau, l'activation des processus biologiques, les cultures amélioratives. On recommande comme cultures amélioratives sur les solonetz de steppe irrigués la luzerne et, sans irrigation, le Mélilotus, la Rudbeckia hirta, le sorgho etc. En conditions d'irrigation, l'amélioration des solonetz exige 3—4 ans et en culture sèche 5—7 ans. La possibilité d'obtenir des productions élevées pour maintes cultures agricoles (blé, maïs, betterave à sucre, pois chiche, riz, sésame, campanule chinoise etc.) est assurée sur les solonetz améliorés et en conditions d'irrigation. Les dépenses sont récupérées en 1—2 ans.

ZUSAMMENFASSUNG

Es werden verschiedene in manchen Zonen des Landes angewendete Solonetz-Meliorationsmethoden erörtert. In der UdSSR nehmen die solonetzartigen Böden etwa 100 Millionen ha, hiervon ungefähr 10% in der Tschernosemzone mit Sodaversalzung ein. Ungefähr 90% der Solonetz- und solonetzartigen Böden, die einen Cl-SO_4 und SO_4-Cl Versalzungstyp aufweisen, sind in den kastanienfarbigen und Braunerdenzonen gelegen. Die Soda (alkalischen)-Solonetzs werden meistens durch Anwendung von chemischen Stoffen – Gips, $CaCl_2$ und verschiedenen Abfälle der chemischen Industrie ($Fe_2(SO_4)_3$; H_2SO_2 u.a.m.) verbessert. Dauerfeldversuche in der Ukraine und im Transural mit Gipsanwendung auf Auensolonetz weisen eine 1,5-bis 2,0 m al höhere Ertragszunahme im Vergleich zur Kontrollparzelle auf. Solonetzs mit Cl-SO_4 und SO_4-Cl Versalzung werden durch einen Komplex von landwirtschaftlichen Massnahmen (agrobiologische Methoden) verbessert, die Bodenbearbeitung, Wassererhaltung, Aktivierung der biologischen Prozesse, Verbesserungskulturen einschliessen. Als Verbesserungspflanzen sind auf bewässertem Steppensolonetz Luzerne und ohne Bewässerung Melilotus, Rudbeckia hirta, Sorghum usw. empfohlen. Unter Bewässerungsverhältnissen erfordert die Solonetzverbesserung 3 bis 4 Jahre, unter Trockenfarmerei 5 bis 7 Jahre. Die Mäglichkeit hoher Erträge bei manchen Kulturpflanzen (Weizen, Mais, Zuckerrübe, Kichererbse, Reis, Sesam, chinesische Glockenblume u.a.m.) auf melioriertem Solonetz unter Bewässerungsverhältnissen ist sichergestellt. Die Auslagen werden in 1 bis 2 Jahren gedeckt.

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THE SODA-SOLONCHAK IN THE NORTHEAST PART OF CHINA AND THE EXPERIENCES IN GROWING RICE FOR THE AMELIORATION OF SOILS

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I. THE ORIGIN AND CHARACTERISTICS OF SODA-SOLONCHAK

1. *The Distribution and Origin of Soda-Solonchak*

The soda-solonchak in the north-eathern Hiern part of China is distributed primarily within the territory located from latitude 43 to 48°N and from longitude 121 to 126° E. It is estimated that it covers an area of about two million hectares.

This region forms a part of the forest steppe, and is subject to the steppe climate. Ordinarily, the mean temperature in January fluctuates from — 16 to 24°C, and that in July from 20—24°C. Its annual rainfall averages 400—600 mm and the rate of its annual evaporation is calculated to be between 1,000 to 1,600 mm.

Geomorphologically, this region is a sedimentary and alluvial plain lying between two rivers, namely, Sung Hua Kiang and Nun Kiang. In some localities where streams are closed up, there are a number of small lakes. Saline soils are mainly distributed in low river terraces, in lowlands bordering lakes and in other depressions.

The soil parent material of consists chiefly of medium and heavy loam. The slope is slight and water drains off slowly. The depth of the ground water table varies from 1 to 3 metres. The rate of mineralization of the ground water is measured to be 0.2—1—2 grams per litre, and in some of the saline lands, this rate may reach 4 grams per litre. As a rule, it is sodium bicarbonate water.

2. *The Sources of Salts in Soils*

The saline soils in this region have been distributed not only in lowlands of the recent deposits, it is found in higher terrace as well. This peculiar phenomenon in distribution is directly related to the sources of salts.

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In the surrounding mountainous areas of this region, granite and black basalt are extensively distributed. Owing to the combined effect of weathering and geochemical processes, the salt contained in soils is being continually carried away from highlands to lower places. This is one of the sources of salts in the local soils.

But there is another source, and this is the stratum of saline rocks with its mineralized subterranean water. This point will be explained with analytical data in tables 1 and 2.

As shown in the above tables, the total amount of salts contained in the bedrocks deeply hidden underneath the plain, including the stratum of fine rocks at the depth of 200—500 meters, may amount to 0.2—0.4%, soda being its dominant constituent. Saline bedrocks of this kind are rather common in this region. The rate of mineralization of some well and spring waters may reach 0.4—0.7 grams per litre. The salt content in these waters is dominated by the bicarbonate of sodium. This coincides with the composition of the salts contained in the local saline soils including those to be found in higher terrace.

3. *The Characteristics of Soda-Solonchak*

Generally speaking, the soda-solonchak in this region has been formed by the effect of weakly mineralized ground and surface waters. The salt in soils is accumulated mostly in the surface layer, usually from 0.5 to 1%, and in rare cases, it may be greater than 2%. Of the whole salt content, soda is always the integral part which amounts to more than 70—80%, while elements of chlorides and sulphates are insignificant. As a rule, its pH value varies from 8.5 to 10.0. All are distributed in spots.

According to the above table, the salt content in the surface layer of this saline soil does not seem to be very high, but it contains a considerable amount of soda, and its pH value is so high that is causes a great detriment to the growth of plant root system. Furthermore, its physical property is bad, being difficult for the water to penetrate. It belongs to such types of saline soils that it is rather hard to get them improved.

Table 1

Salt contents in bed rocks

Locality	Depth (m)	pH	Total salt contents %	gm in 100 gm rock						
				CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na
HB-46	220	9.5	0.401	0.074	0.182	0.005	0.008	0.001	0.001	0.130
	308—318	9.5	0.353	0.064	0.184	0.007	0.003	0.001	0.001	0.093
	437—440	9.5	0.402	0.108	0.132	0.008	0.012	0.002	0.001	0.139
	473—476	8.5	0.289	0.010	0.137	0.039	0.012	0.002	0.002	0.087
HB-52	381	9.2	0.411	0.050	0.170	0.035	0.022	0.002	0.001	0.131
	449	9.3	0.454	0.075	0.128	0.054	0.039	0.002	0.001	0.155
	490	9.5	0.415	0.106	0.104	0.044	0.008	0.003	0.001	0.149

Table 2

Salt contents in spring and well waters

Source of water	pH	Total salt contents	gm/l						
			CO_3	HCO_3	Cl	SO_3	Ca	Mg	Na
HB-19 spring	8.0	0.437	—	0.246	0.009	0.010	0.075	0.007	0.090
HB-22 well	8.0	0.736	—	0.508	0.019	0.010	0.072	0.010	0.117

Table 3

The Soluble Salts of the Soda-Solonchak Locality No. 10

Depth (cm)	Residue of evapo-ration %	m.e./100 gm. soil							
		CO_3	HCO_3	Cl	SO_4	Ca	Mg	N	pH
0—5	0.707	0.13	4.64	—	0.35	0.19	0.32	4.61	10.2
5—11	0.600	0.17	4.53	—	0.34	0.35	0.27	4.43	10.0
11—27	0.076	—	0.87	0.16	0.52	0.36	0.31	0.83	8.1
27—65	0.221	0.04	1.75	0.12	0.16	0.17	0.31	1.58	9.4
65—91	0.067	—	0.75	0.14	0.17	0.30	0.34	0.42	8.1
91—115	0.400	trace	0.76	0.15	0.22	0.36	0.36	0.41	8.0

Water extraction 1 : 5.

II. GROWING RICE FOR THE AMELIORATION OF SODA-SOLONCHAK

1. *Reasons for Launching this Project*

According to the experience gained in different countries, the procedure for the amelioration of soda-solonchak usually consists of several steps. The first step to be taken is to use various methods to lower the level of ground water down to below the critical depth; the second step is to supply the soil with gypsum; the third step is to wash off the salt which is superfluous and harmful to the plant; the fourth step is to develop the cultivation of dryland crops and to control the irrigated water with specified norms so as to prevent salts from turning up.

But in the lowland districts, where water can hardly be drained, the procedure mentioned above is likely to be inadvisable and inapplicable. The Kuo-Chien-Chi irrigated region of Chilin province in northeast China is a typical case of this kind.

This irrigated region lies in the lowland along Sung Hua River. Its ground water is 1.5—2 metres below the surface, and in some lower parts the water level is almost at par with the river surface. During the summer when the river water rises, the river has constantly been a source of supply to the underground water, causing it to raise its level near to the surface. Thus, it is a very difficult job to lower the ground water down below the critical depth. However, thanks to the fact that there is an abundant supply of

water, the lowlands can be utilized to grow rice, since it is not necessary to have deep channels for drainage. The only thing that needs to be done is to change the surface water at intervals in order to dilute its salt content. In this way, it will be possible to achieve the effect of both utilization and amelioration at the same time.

2. *Main Achievements Gained in a Period of 9 Years*

Since 1955, the Institute of Forestry and Pedology, Academia Sinica, co-operating with the authorities of Kuo-Chien-Chi irrigation Controlling Office, has undertaken the task of growing rice for the amelioration of Soda-Solonchak at Kuo-Chien-Chi irrigated region of Chilin Province. In a course of 9 years, through numerous periodic observations and repeated experiments, the following achievements have been attained:

The volume of irrigated water in the rice field has been reduced year by year. During winter and spring seasons, the level of ground water may descend to the annual average depth. The salt contained in the ground water and in the soil at root distributing layer is conspicuous for its descending process. No application of gypsum is necessary. Under the proper management, the rice grows excellently. In 1955 when this experiment was first started, for every hectare of land the average volume of irrigation water amounted to 35,000 cubic metres. It was enormous. But in the ensuing year, 1956, it was reduced to 15.000 cubic meters. And in recent years a volume of 7 000—8 000 cubic meters per hectare has been found to be sufficient.

For years, the level of ground water was hidden at a depth of about 2 meters, and it remained steady. Due to the effect of irrigation, the range of seasonal variations is somewhat wide. But in winter and spring seasons the water level tends to descend to the annual average depth. During the flood season, however, the ground water in the irrigated area is apt to rise with the rising of rivers, thus making it difficult for drainage in the growing period of crops. But when the dry season approaches, the superfluous water is being drained, and along with it a portion of salt will surely be carried away.

Basied on an analytical study of the accumulated data from a number of observation wells, it is found that the soils that have been irrigated for several consecutive years, may be classified in accordance with the variations of salt content into three groups. Those whose salt content tends to rise, constitute only 22%; those whose salt content remains unchanged, 30%; and those whose salt content is inclined to be reduced, constitute 48%. About 50 per cent of the salt content of the soil in the layer between 0 to 65 mm have been reduced, whereas the soil in the layer between 0 to 30 mm shows an apparent tendency of being desalted. The physical property of the soil has also been improved to a certain extent.

Among various treatments for soil improvement, the combination of gypsum with farm manure and the combination of peat with farm manure

have been proved to be effective in reducing the salt content in soil. When only the farm manure or gypsum or medium sand is used, the effect of all of them is good. All things being considered, the utility of farm manure is very great. It will help in improving the soil and supplying the plant with nutrients as well. It has a considerable significance in the practices of farm production.

With long years of experience gained in this undertaking, up an entire set of comparatively systematic measures for the growing of rice in Soda-Solonchak has been summed.

As a result of rice growing, the quality of the soil has been gradually improved. The yields of rice grown in an area of two hectares with various treatments have been increased year by year. In 1955 when this project was first launched, the average yield of rice was less than 700 kilograms per hectare; four years later in 1959 it reached 5,000 kilograms per hectare, And similar results have been accomplished in the extension districts.

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SUMMARY

The soda-solonchak in the north-eastern part of China is found to be formed by the effect of weakly mineralized ground and surface waters which are dominated by the bicarbonate of sodium. Of the total salt contents in soda-solonchak, soda is always the integral part which amounts to more than 70—80%. Its pH value varies from 8.5—10.0. Its physical properties are bad. But since the superfluous water could be drained in winter, it is feasible and profitable to reclaim the soda-solonchak gradually by growing rice with proper irrigation and applying certain amounts of farm manure in the growing seasons.

RÉSUMÉ

On constate que le solonchak à soude du nord-est de la Chine est formé par l'effet des eaux souterraines et de surface, faiblement minéralisées, eaux qui sont dominées par le bicarbonate de soude; sur la teneur totale en sel, des solonchaks à soude, le carbonate de soude est la partie composante qui s'élève à plus de 70—80%. Ses valeurs pH varient de 8,5 à 10,0. Les propriétés physiques sont mauvaises.

Étant donné que surplus d'eau peut-être drainé en hiver, il est possible et profitable d'améliorer les solonchaks à soude, par la culture progressive du riz à irrigation convenable tout en appliquant une certaine quantité de fumier pendant la période de végétation.

ZUSAMMENFASSUNG

Der Natrium-Solontschak im Nordosten Chinas wurde als durch die Einwirkung von schwach mineralisierten, von Natriumkarbonat beherrschtem Grund- und Oberflächenwasser gebildet erfasst. Auf den Gesamtsalzgehalt des Natrium-Solontschaks entfallen stets auf Natrium das den Hauptbestandteil bildet, mehr als 70—80%.

Seine pH-Werte schwanken zwischen 8,5—10,0; die physikalischen Eigenschaften sind schlecht. Aber seitdem das überschüssige Wasser im Winter dräniert werden konnte, ist es möglich und vorteilhaft, Natrium-Solontschaks stufenweise durch Reiskulturen mit geeigneter Bewässerung und mit Anwendung gewisser Mengen von Stallmist in der Wachstumsperiode nutzbar zu machen.

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PROBLEMS IN THE RECLAMATION OF SOME SALINE SOILS IN THE U.S.S.R.

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The Soviet Union is a country of extensive agriculture on irrigated lands. The increase of irrigated areas in this country is characterized by the following figures:

Irrigated in the U.S.S.R. during different years (in th. of hectares)

1913	*1923*	*1928*	*1932*	*1937*	*1940*	*1961*
3,597	2,226	4,171	5,325	5,871	6,322	9,700

One of the main problems of irrigation farming, especially in the "cotton belt" of the U.S.S.R., is still a struggle against salinization hazards.

In the U.S.S.R., irrigation agriculture had existed in many oases for several thousands of years. In the past onlypart of the area was irrigated within non-drained oases. Saline ground waters shifted to nonirrigated lots and evaporated leaving the salt behind. With such a system in oases with unfavourable melioration conditions, from 25 to 30% of the total area is irrigated.

The remaining part acts as a "dry or evaporatory drainage". An attempt to increase irrigated areas under such conditions without an artificial drainage resulted in a general rise of the ground water table and a salination of previously desalted soils. The possibilities of the "dry drainage" were gradually exhausted and began to conflict with the aims of extending and intensifying irrigation farming. Worth attention is the available experience of a fundamental improvement of saline soils in a number of oases by artificial drainage, for instance, in Vakhsh valley and the Khorezm oasis.

Drainage construction in the Vakhsh valley became extensive in post-war years. At present the extention of the collector-drainage system over the entire area comes to an average of 12—13 linear metres per 1 ha. The depth of the collectors is 3.0—3.5 m and that of the drains 2.0—2.5 m. As a result of the collector-drainage system, the ground water table sank by 0.5—1 m. and the mineralization of ground waters decreased. With an improvement of the collector-drainage system and an increase in the supply of water in the oasis, the leaching of salts from the irrigated territory reached 1.2 m/t for

1960. The reclamation of saline soils proceeded with a constantly increasing effect (table 1).

Table 1

Changes in the area of saline soils on old arable lands of Vakhsh valley belonging to colective farms, during the period form 1945 to 1961 (in%)

Category of soils	Years			
	1945	1950	1954	1961
1. Non-saline, weakly and medium-saline soils	49,6	65.6	75.1	85.0
2. Strongly saline soils and solonchaks	50.4	34.4	24.9	15.0

The greatest leaching of salts and a stable desalinization proceeds with the oflow drainage waters in amounts of 40—50% of the total watering dose. After the desalting of soils and the removal of surplus salts, the discharge of drainage waters from Vakhsh valley should, according to estimates, remain at about 25—30% of the total watering dose for the oasis.

The melioration experimenting of saline soils in Vakhsh valley indicates that a deep open horizontal drainage system in a good state, fully quarantees the desalinization of soils in the entire oasis. At present experiments on a vertical drainage are conducted. In future, with cheap electrical power from the hydroelectric plants of Vakhsh valley, the horizontal drainage will be partly replaced by a vertical drainage. Of no lesser interest is an experiment of industrial melioration of soils in the Khorezm oasis. Before the construction of the drainage system (Rachinsky, Sosedko), many soils were subject there to salinization. The construction began in 1945—1947 with the lenghening of the drainage-collector system up to 2,820 km (17 m per 1 ha). The average depth of the drains is 2.2 m and of collectors — 3.3 m. The total yearly salt discharge beyond the oasis through the drainage system amounts to 17,841 t. The discharge of drainage waters beyond the oases reaches 15—25% of the total watering dose. By melioration in progress, not only irrigated soils have been desalted, but also the top layer of ground waters became freshened up to 1—3 gram/litre. The removal of mineralized ground waters and leachings beyond the limits of the oasis (1957) permitted to increase considerably the area under cotton and to raise the average yield for the oasis to 6.65 quintals/ha in 1947 and to 31 quintals/ha in 1963.

An example of a more complicated meliorative object is the Kura-Arax lowland. Here the construction of a deep horizontal drainage permitted to overcome the extremely complex forms of primary and secondary salinization that may arise under conditions of the ascent of deep pressure brines. Data on the salinity of the upper 100 cm of soils are presented in table 2.

The experiments with an artificial horizontal (closed) drainage on Mugansk meliorative station proved to be successful. However, a further construction of open drainage in a number of regions of the lowland encountered numerous natural and economic obstacles. Only when they were over-

come serious successes have been recorded. By this time within the Mugano-Salian part of Kura-Arax lowland alone 3,700 km of drains and collectors of an open type have been constructed over an area of 159 th.ha. The collector-

Table 2

Soil areas by the degree of salinisation in the massifs of Kura-Arax lowland during 1937—1940 (in %)

% of water soluble salts in the soil, 0—100 cm	Northern Mugan	Salian steppe
less than 0.5	34.8	2.3
0.5—1.0	33.6	29.3
1.0—2.0	27.3	46.0
> 2.0	4.3	18.8

drainage system with the help of 16 pumping stations removes yearly an average of about 850,000 m³ of discharge water beyond the limits of Kura-Arax lowland.

During the period from 1954—1962 about 430 tons of salts have been removed from each hectare of drained area (up to 50% of salt stocks) beyond the limits of Mugano-Salian massif together with the drainage runoff. The reclamation of the lands use reached 0.58 in 1961 and doubled as compared with its premeliorative period. About 1/3 of collective farms have a land use coefficient exceeding 0.7. It is technically possible to carry out meliorative work everywhere in the country if necessary. Its scale is constantly increasing. Such work has been started now in most oases where the lands are subject to salinization. Meliorative science and practice devote special attention to the problem of spacing drains and their depth depending on different cases; movement of saline solutions from leached soils into drains is subject to an extensive discussion.

Practice of a number of farms and Soviet literature have proved the advantage of maintaining a meadow-water regime on irrigated lands (Mugan, Zolotoordin, Chardzhou, Bukhara and other experimental stations, papers by Kovda, Rabochev, Legostaev, Antipov-Karataev, Konkov, Volobuev and a number of other researchers). It is sometimes thought that shallow drainage is the best in creating a favourable meadow-water regime, forgetting that every drainage during the meliorative period is, first of all, aimed at a removal of salt accumulations beyond the root zone. The advantages of a meadow-water regime can become apparent, as has been first indicated by V.A. Kovda, only after a sufficiently complete freshening of the top layer of soil ground waters. If not, the water remains mineralized, a shallow drainage will result in a meadow-solonchak process with all associated negative after-effects.

When the water regime of the soil corresponds best the meadow-sierozem type of soil formation, the deep horizontal drainage guarantees a quick desalinization of soils. In time a necessary freshening of the top layer of saline ground waters becomes possible. To achieve this it is enough to maintain

a leaching regime of irrigation. Only after that the creation of a meadow regime on irrigated lands becomes possible. Certain care must be taken so as not to use up completely the reserves of the freshened layer of subsoil water for the transpiration of the cultivated vegetation.

A horizontal drainage, especially of an open type, has a number of defects (great volume of earth-excavation work, loss of usuable area, neccessity of repairs under complicated conditions, difficulty of technical control over the state of a closed drainage system etc.). Vertical drainage has some advantages as compared with the horizontal type. However, its practical testing with meliorative aims has started in the U.S.S.R. comparatively recently. Most promising for a vertical drainage are regions, where layers meet at a certain depth with gravels and sand with a high water content and water yield. By estimates (Mikhelson) under such conditions, the meliorative effect and a lowering of the ground water table at the expense of the total water discharge is very low-only about 5%.

Meliorative measures and their scientific summarization were taking place in the U.S.S.R. with the application of an old irrigation technique. At the present time the irrigation technique is being perfected. Some meliorators had the impression that the introduction of a new technique in irrigation would exclude a rise of the ground water table and thus the necessity to fight a secondary salinization of the soils through drainage systems may be eliminated by itself.

Recently V. A. Kovda has generalized data on soil-meliorative evaluation of irrigated oases. The systems of meliorative measures worked out for different oases, were based on a natural-historical background with due consideration to the present irrigation technique. On the basis of available experience and theoretical ideas it is possible to conclude that even with a more economical and modern system of irrigation a rise of the ground water table will take place at non-drained oases. Consequently, they need the construction of a drainage system for the removal of ground waters. Of special interest is the type of oases, where mineralized ground waters—before irrigation—were at a depth of 15—20 m and more. In such territories the ground in the aeration zone is usually more or less saline. The practice of irrigating such lands did not escape raising the ground water table and a secondary salinization. There is no sufficient basis to orientate the meliorative thought to a drainless irrigation of saline lands.

Under definite conditions, methods of watering will influence the solution of meliorative problems. On saline lands a correctly chosen irrigation regime can alleviate the toxic effect of salts and encourage desalinization. A happy combination of sprinkling irrigation with water flooding irrigation in winter found for Pakhta-Aral state farm, gave good results on old cultivated lands. However, this is not the only way and, for the time being, there is no reason to give up under all conditions the former methods of watering, including furrow irrigation. The practice of land reclamation—when it is subjected to a quick salinization under irrigation—tends to the necessity of finding a complex of meliorative measures simultaneously with irrigation construction. This should also include a construction in time of drainage systems. In future, in the pro

cess of using reclaimed lands drainage, it helps to maintain a fresh meadow-moisture on irrigated soils. Inasmuch as this does not exclude a rise of a solution from the capillary fringe of ground waters, the latter must be maintained in a definite state by a periodical leaching regime of irrigation with a removal of concentrating salts.

All the above mentioned permits to assume that a new stage of irrigation-meliorative construction in the U.S.S.R. raises a number of new problems before our research institutions. They have been only partly referred to in the paper. Yet there is no reason to think that a necessity has arisen in a number of soil meliorative problems to reconsider the previously established concepts of Russian soil scientists Bushuev, Dimo, Malygin, Rozov, Rozanov that are developed now by V. A. Kovda, Antipov-Karataev, Legostaev, Rabochev and other scientists.

SUMMARY

The expansion of irrigated areas in the U.S.S.R. induces melioration and development mostly of saline soils. To struggle against and prevent new secondary salinization, application of new irrigation technics, is not enough. On areas without natural ground water flow, irrigation practically always leads to its uplift independent of filtration losses.

The necessity of artificial drainage for the development of undrained oases in future is substantiated. A horizontal drainage system in a dry ground is less expensive and technically easier. Shortcomings in a shallow horizontal drainage, as to a deeper one are considered. Examples are cited for the meliorative status of developed lands without drainage (evaporative or dry drainage) and desalinization of vast areas of land artificially drained in the U.S.S.R.

RÉSUMÉ

L'extension des surfaces irriguées en U.R.S.S. Simplique surtout l'amélioration et la mise en culture de sols salins. L'application de la technique moderne d'irrigation n'est pas suffisante pour combattre la salinisation existente ou pour prévenir une salinisation secondaire nouvelle. L'irrigation des terrains dépourvus d'écoulement naturel des eaux souterraines conduit presque toujours au relèvement de leur niveau, indépendamment des pertes par infiltration.

La nécessité du drainage artificiel pour assurer à l'avenir le développement des oasis dépourvues de drainage naturel est démontrée. Dans un terrain sec, le système de drainage horizontal est le moins coûteux et le plus facile à établir. Les auteurs discutent les inconvénients du drainage horizontal peu profond. Ils citent des exemples de résultats obtenus dans l'amélioration des terres sans drainage (drainage par évaporation ou à sec) et la désalinisation de vastes étendues de terrain drainées artificiellement en U.R.S.S.

ZUSAMMENFASSUNG

Die Ausdehnung der bewässerten Flächen in der UdSSR führt hauptsächlich zur Melioration und Fruchtbarmachung der Salzböden. Um die vorhandene Versalzung zu bekämpfen oder einer neuen sekundären vorzubengen, genügt die Anwendung der neuren Bewässerungstechnik nicht. Auf Flächen, die keinen natürlichen Grundwasserabfluss besitzen, führt die Bewässerung praktisch stets zur Erhöhung der Grundwasser, unabhängig von den Einsickerverlusten.

Es werden Beweise für die Notwendigkeit einer künstlichen Entwässerung in der künftigen Entwicklung der unentwässerten Oasen erbracht. Ein horizontales Entwässerungssystem in trockenem Boden ist billiger und technisch einfacher. Es werden die Mängel einer seichten Horizontalentwässerung im Vergleich mit einer tieferen berücksichtigt. Es werden Beispiele für den Meliorationszustand entwickelter Gelände ohne Entwässerung (Evaporativ-oder Trockenentwässerung) und für die Entsalzung in ausgedehnten künstlich entwässerten Landflächen der UdSSR angeführt.

DISCUSSION

K. VAN DER MEER (NETHERLANDS). In the paper, the disavantages of a horizontal drainage and the possibilities of vertical drainage were mentioned. On theoretical basis, a vertical drainage is all right. Experiences elsewhere, however, have shown, that the vertical drain tubes suffer seriously from the corrosive activity of the more or less saline groundwater. A complete destruction of the vertical tubes in 2—5 years time is observed. The question is: How is the corrosive activity of the groundwater in the investigated area to be prevented and how do the investigators think to do it?

R. M. HAGAN (U.S.A.). What is the experience of the U.S.S.R. with corrosion of well casings and other parts of wells used for vertical drainage in saline areas?

V. R. VOLOBUEV. The difficulties which existed in horizontal drainage application had a local character, being conditioned by the lack of resistance of the slipe drains there where the soil was of alcali resistant nature (fine sand).

Concerning the difficulties in vertical drainage application, this is due rather to the hydrological conditions than to the lack of resistance to corrosion of the technical installations; the vertical drainage was efficient only in gravel soil conditions, with great permeability.

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VI. 29

PROBLEME DER REKULTIVIERUNG VERSUMPFTER UND VERSALZENER BEWÄSSERUNGSBÖDEN DER ARIDEN GEBIETE

H. JANERT[1]

Schäden durch Versumpfung und Versalzung des Bodens kommen, wenn auch in sehr verschiedenem Ausmass, in allen ariden bis semiariden Gebieten vor. Besonders stark sind sie in Asien verbreitet und haben namentlich in Indien und China katastrophalen Charakter angenommen, wo 6 bzw. 14 Millionen Hektar fruchtbare Bewässerungsböden verwüstet worden sind. Auch in der UdSSR gibt es 3 Mill. ha versalzener Bewässerungsböden. Es ist verständlich, dass in weit zurückliegenden Zeiten, beispielsweise im Babylonischen Reich des Altertums, keine Möglichkeit bestanden hat, solcher Schwierigkeiten Herr zu werden, weil brauchbare Meliorationsverfahren damals noch unbekannt waren. Heutigentags aber sind die Erscheinungen und Ursachen der Versumpfung und Versalzung bewässerter Böden gründlich erforscht und auch die zur Melioration solcher Böden erforderliche Technik entwickelt worden. An diesen Arbeiten waren unter anderen britische, amerikanische und neuerdings besonders auch sowjetische Wissenschaftler hervorragend beteiligt. Als Beispiel aus jüngster Zeit mögen die Meliorationen in Aserbaidshan genannt werden, die auf Grund umfangreicher, in der Mugan-Steppe durchgeführter Versuche bemerkenswerte Erfolge haben zeitigen können.

Angesichts der grossen verfahrenstechnischen Fortschritte, die bei der Bekämpfung und Verhütung von Versalzungsschäden erzielt worden sind, muss man sich wohl die Frage vorlegen, warum trotzdem solche Schäden noch immer in gewaltiger Ausdehnung vorhanden sind, und dadurch nach wie vor viele Millionen Menschen zu Hunger und Elend verdammt bleiben. Es darf als sicher angenommen werden, dass sich alle für die Bewässerrungswirtschaft verantwortlichen Fachleute nach Kräften bemüht haben, diesem Unheil ein Ende zu bereiten, zum mindesten eine weitere Ausbreitung der Schäden zu verhindern. Leider ist das aber nicht allenthalben gelungen, woraus zu folgern ist, dass in den betroffenen Gebieten besondere Schwierigkeiten vorliegen, welche die Melioration der versalzenen Böden behindern und mit den örtlich verfügbaren Hilfsmitteln nicht überwunden werden können. Sicherlich gibt es in den einzelnen Schadgebieten verschiedenartige Schwierigkeiten, so dass es auch nicht möglich ist, universell anwendbare Meliorationen vorzu-

[1] Greifswald, DEUTSCHE DEMOKRATISCHE REPUBLIK.

schlagen. Die einzige Möglichkeit, mit der praktischen Arbeit vorwärts zu kommen, besteht vielmehr darin, von Fall zu Fall die örtlichen Verhältnisse genau zu analysieren, die wirksamsten Meliorationsverfahren zu erproben und schliesslich einen konkreten Massnahmeplan auszuarbeiten.

Der Verfasser hatte Gelegenheit, in dem indischen Staate Punjab nach diesem Prinzip zu arbeiten, und nachdem die dort gewonnenen Erkenntnisse inzwischen durch Laboratoriumsversuche in Greifswald in Zusammenarbeit mit Dr.V. K. Chawla ergänzt worden sind, hat sich ein klares Bild von der Entstehung der Versalzungsschäden in diesem Gebiet und von den Möglichkeiten ihrer Beseitigung ergeben.

Schwere und ausgedehnte Versalzungschäden sind nur im Einzugsgebiet des Indus und des Ganges aufgetreten, und zwar ausschliesslich im Bereich der sogenannten Kanalbewässerung, nicht aber bei der Bewässerung aus Brunnen oder Regenwasser-Staubecken (Tanks), deren Verbreitung aus der in Abbildung 1 wiedergegebenen Bewässerungskarte von Indien und Pakistan zu erkennen ist.

Aus dieser Tatsache ist zu folgern, dass Versalzungsschäden nur dann zu gewärtigen sind, wenn dem Boden Fremdwasser zugeführt wird, das gewisse, wenn auch nur gering und unbedenklich erscheinende Salzmengen enthält. Findet das zugeführte Fremdwasser gute Abzugsmöglichkeiten durch ausreichende Vorflutanlagen oder durch Versickerung in den Untergrund bei tiefliegendem Grundwasserspiegel, dann kommt es nicht zu einer schädlichen Salzanreicherung im Boden. Ist aber die Vorflut unzureichend, so führt dies zu einem allmählichen Anstieg des Grundwasserspiegels, bis das kapillar aufsteigende Wasser die Oberfläche erreicht. Zu diesem Zeitpunkt beginnt gewöhnlich die Salzanreicherung im Boden, weil bei behindertem Wasserabfluss die Wasserverdunstung zunimmt, was einen entsprechenden Anstieg der Salzkonzentration zur Folge hat. So ist es zu erklären, dass manche Böden jahrhundertelang mit bestem Erfolg bewässert werden konnten, bis plötzlich die Erscheinungen der Versumpfung und Versalzung einsetzten und die Böden im Laufe weniger Jahre unfruchtbar machten.

Über diese Zusammenhänge bestanden zunächst mancherlei Unklarheiten, gerade auch bezüglich der Herkunft der Schaden bringenden Salze. Sehr verbreitet war die Ansicht, dass sich die Salze schon früher im Boden befunden haben müssten und erst nach Einführung der Bewässerung allmählich gelöst und mit dem Wasser an die Oberfläche gelangt sind. Man konnte sich auch nicht vorstellen, dass die Salze aus dem zugeführten Wasser stammen sollten, das man ganz richtig als „Süsswasser" bezeichnete. Um diese Frage zu klären, haben wir 14 Wasserproben aus den wichtigsten Zuleitern des Katastrophengebiets, aus Flüssen und Kanälen untersucht, deren Beschaffung der freundlichen Hilfe von Dr. Uppal, Amritsar, zu danken ist. Im Mittel der untersuchten Wasserproben wurde ein Salzgehalt von 2,34 g/l festgestellt, der noch als mässig bezeichnet werden kann. Der Natrium-Adsorptionskoeffizient betrug 0,4, war also nicht sonderlich hoch, reicht aber vollständig aus, um das Zustandekommen der verheerenden Versalzungsschäden zu erklären.

Die Versalzung hängt nämlich nicht allein vom Salzgehalt, sondern auch von der Menge des aufgebrachten Wassers ab, die sehr hoch ist und für eine

Bewässerung mit 30 cm Wasserhöhe angesetzt werden muss, was 3 000 m³/ha entspricht, mit einer Salzmenge von 7 000 kg/ha. Da meist 5mal pro Jahr bewässert wird, beträgt also die jährlich zugeführte Salzmenge 35 t/ha.

Solange das im Überschuss aufgebrachte Wasser abfliessen oder in den Untergrund versickern kann, ist selbst diese enorme Salzzufuhr unbedenklich.

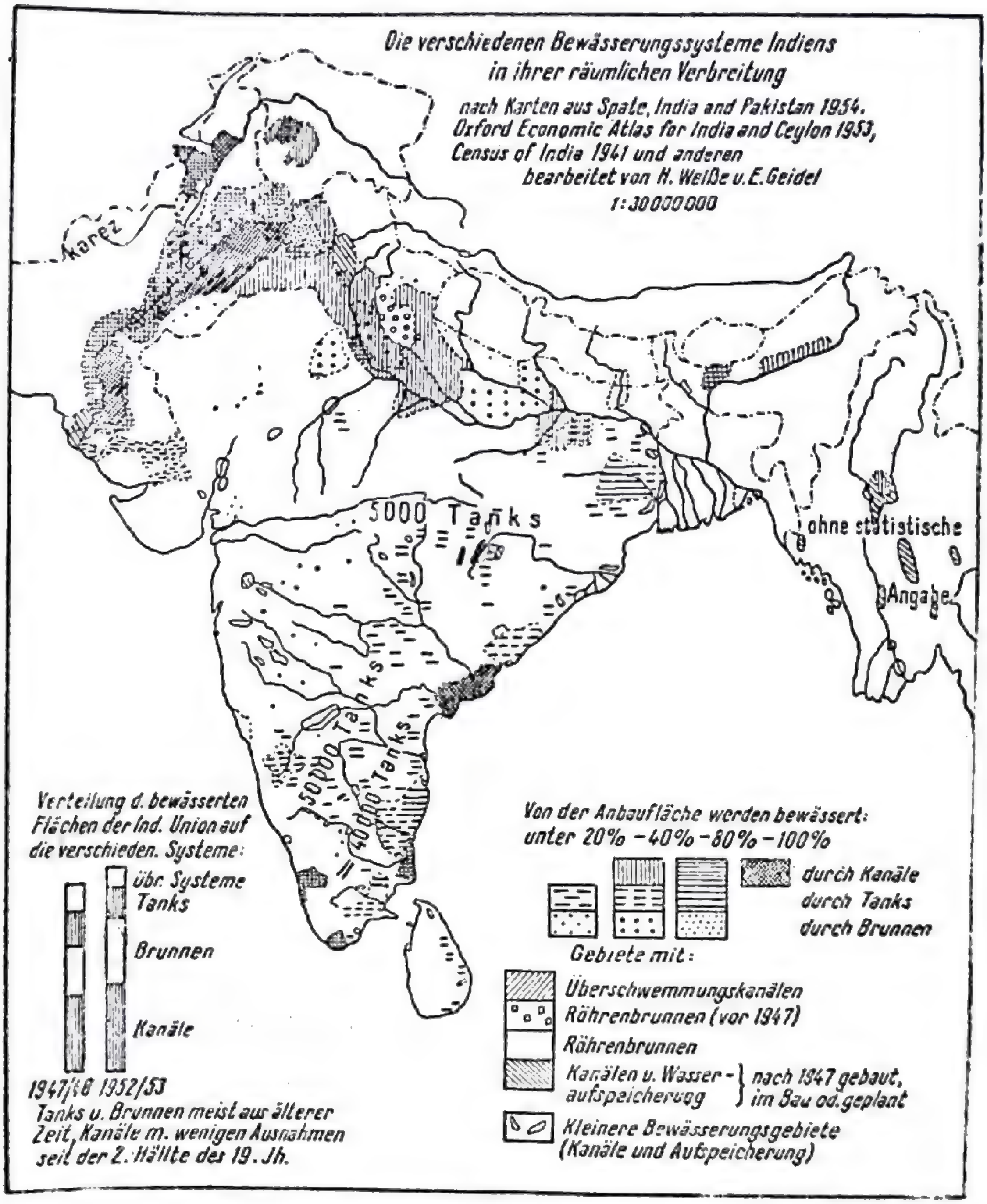

Abb. 1. Bewässerungskarte von Indien und Pakistan.

Lieder aber ist die Vorflut in den Schadgebieten völlig unzureichend, und der Grundwasserspiegel liegt nahe oder gar über der Geländeoberfläche, so dass ein mehr oder weniger grosser Teil des Überschusswassers verdunsten muss, und gerade dadurch kommt dann eine zu hohe, schädliche Salzkonzentration zustande.

Für die Melioration der versumpften und versalzenen Bewässerungsböden ist demnach die Schaffung ausreichender Abflussmöglichkeiten für das überschüssige Wasser absolut vordringlich. Leider bestehen aber in dieser Hinsicht ausserordentliche Schwierigkeiten, weil die ganze Wasserwirtschaft des Punjab, ebenso wie in anderen indischen Staaten, einseitig auf die Bewässerung eingestellt ist. Das ist selbstverständlich, weil es sich um Gebiete handelt, die während des grössten Teiles des Jahres, nämlich ausserhalb der Monsunzeit, anhaltender Dürre ausgesetzt sind. Infolgedessen hat man beim Bau der Bewässerungskanäle gar nicht daran gedacht, dass die ausgedörrten Länderein jemals unter einem schädlichen Wasserüberschuss würden leiden können, und hat daher die Sorge um die Entwässerung des Landes völlig vernachlässigt. So ist eine Situation entstanden, deren Ernst an jedem beliebigen Ausschnitt aus dem Kanalsystem demonstriert werden kann, wie es in Abbildung 2 an einem Beispiel aus dem Distrikt Patiala geschehen ist. Alle in der Abbildung sichtbaren schwarzen Linien stellem mit Ausnahme einiger weniger, als solche kenntlicher Eisenbahnen und Strassen, Bewässerungskanäle dar, die von einem Hauptkanal (Kotla Branch) abzweigen. Auffällig ist an diesem Kanalnetz das Fehlen eines klaren Systems, was daran zu erkennen ist, dass sich an mehreren Stellen Kanäle kreuzen. Das wäre zweifellos sachlich vermeidbar gewesen, ist aber aus den früheren, komplizierten Besitzverhältnissen zu erklären, die jedem Fürsten oder Grossgrundbesitzer gestatteten, die Führung der Kanaltrassen nach eigenem Belieben anzuordnen.

Da alle Bewässerungskanäle als aufgedämmte Kanäle gebaut worden sind, entstehen allenthalben, besonders aber an den Kreuzungsstellen unerwünschte bis katastrophale Behinderungen des oberflächlichen Wasserabflusses, und das ganze Land erscheint aufgeteilt zu sein in Flächen, die wie bei einem Teller von hohen Rändern, nämlich den aufgedämmten Kanälen, begrenzt sind. Selbst wenn in die Kanaldämme—meist nachträglich—Durchlässe eingebaut worden sind, reichen diese doch gewöhnlich nicht aus, um das aus Niederschlägen oder von einer Bewässerung herrührende Überschusswasser genügend schnell abzuführen.

Natürlich hat man im Ministerium für Bewässerung und Wasserkraft längst erkannt, dass Entwässerungsanlagen notwendig sind, aber man muss anerkennen, dass es ganz ausserordentlich schwer ist, jetzt das nachzuholen, was vor hunderten von Jahren, vor dem Bau der Bewässerungsskanäle, versäumt worden ist. Es ist auch verständlich, wenn man sich bemüht, die enormen Aufwendungen für den Bau ganz neuer Entwässerungssysteme zu vermeiden und vorerst Behelfslösungen zu finden. Allerdings ist es zweifelhaft, ob mit solchen Behelfsmassnahmen, wie sie in grossem Umfang geplant worden sind, ein bleibender Erfolg erzielt werden kann.

In Abbildung 3 ist ein Ausschnitt aus einem für den zunächst eingeschlagenen Weg typischen Entwässerungsprojekt wiedergegeben. Es ist zu erkennen,

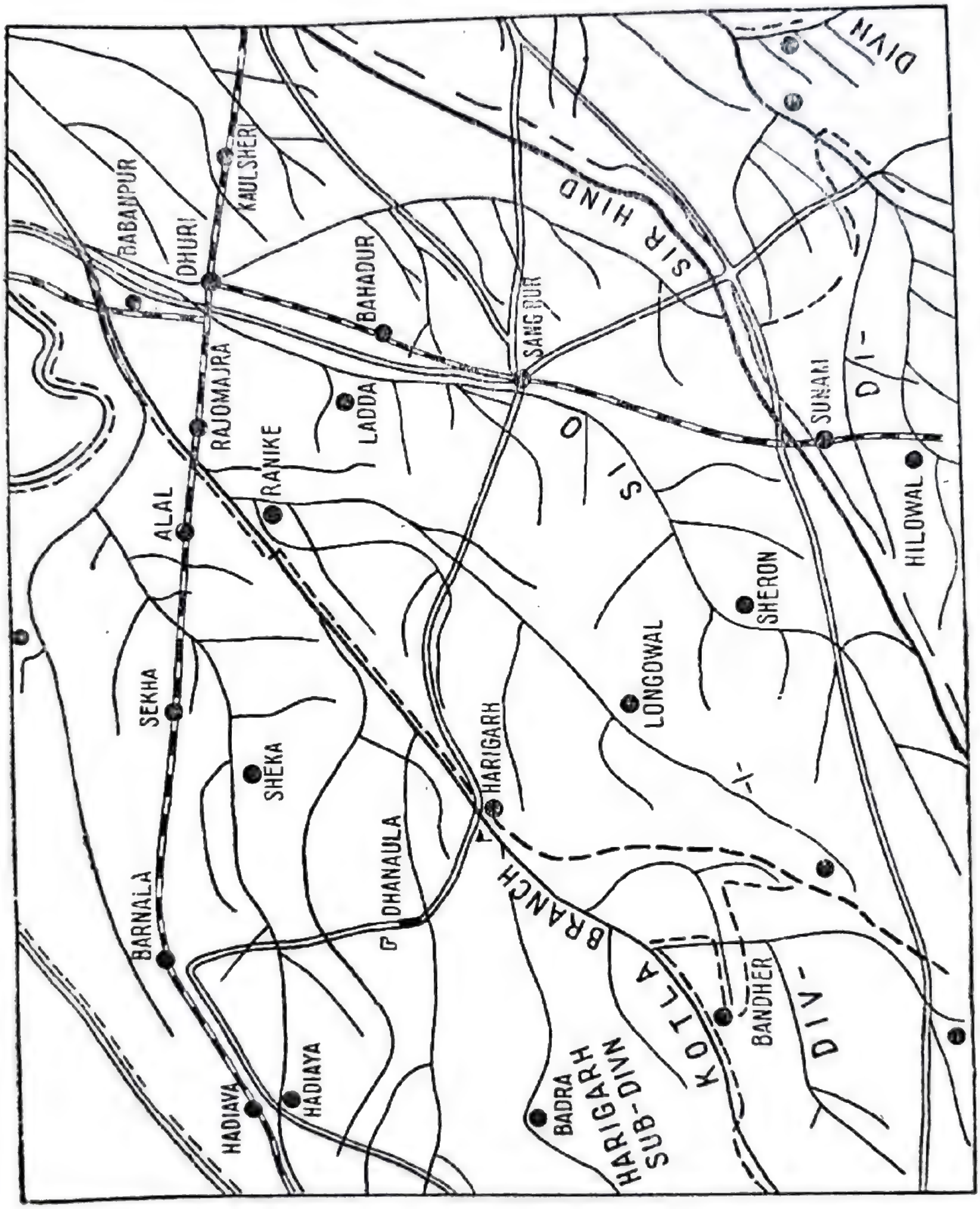

Abb. 2. Ausschnitt aus dem System der Bewässerungskanäle im Distrikt Patiala.

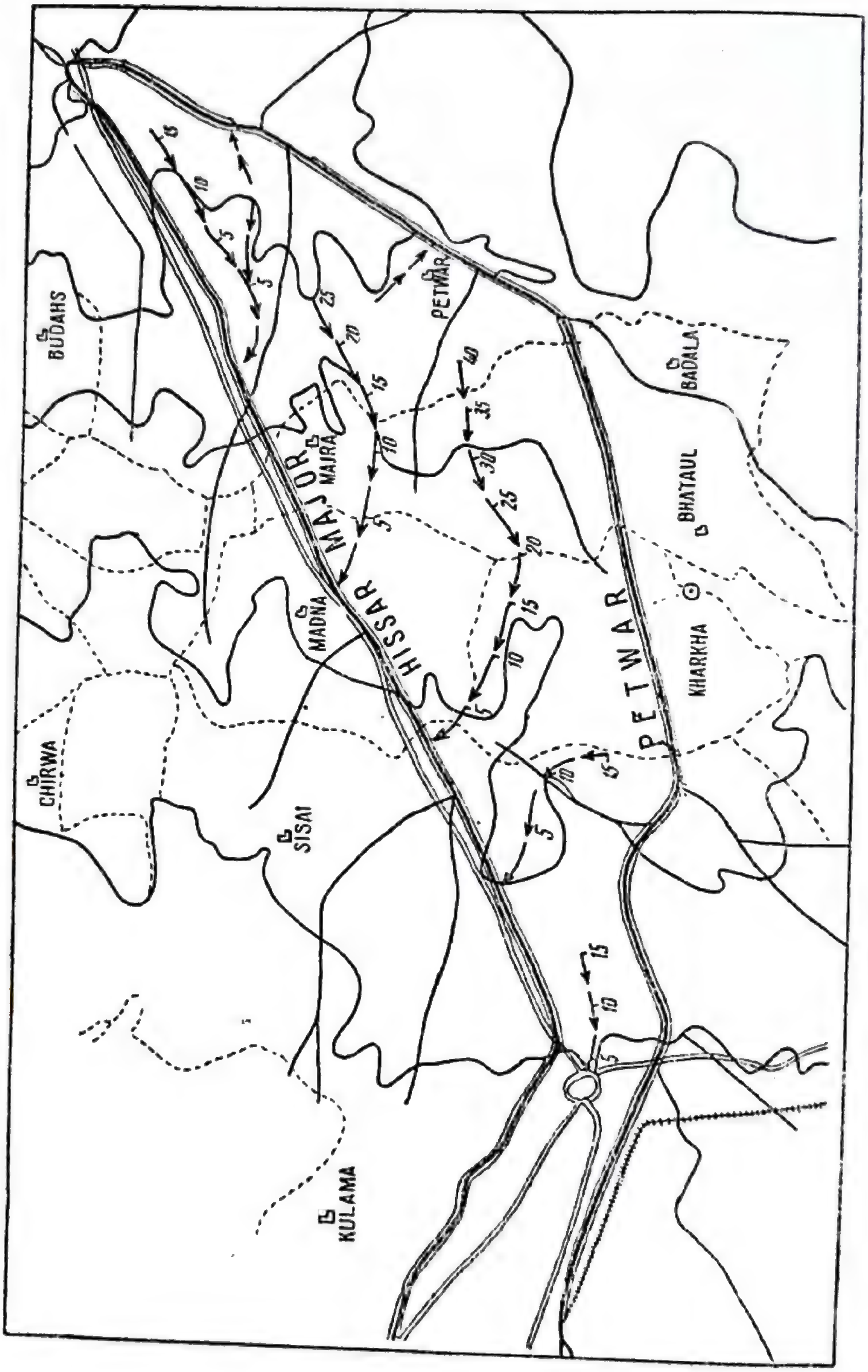

Abb. 3. Ausschnitt aus einem Entwässerungsprojekt.

dass hier in unmittelbarer Nähe der Stadt Hansi, durch den Hissar Major-Kanal und den von ihm abzweigenden Petwar-Kanal, eine Fläche von ca 13 000 ha umgrenzt wird, die wie ein Teller zwischen den aufgedämmten Kanälen liegt und zu einem beträchtlichen Teil unter Wasser steht. Die gestrichelten Linien zeigen den Verlauf der projektierten Entwässerungskanäle, die jedoch nicht in einen entsprechend aufnahmefähigen Vorfluter einmünden, weil ein solcher gar nicht vorhanden ist, sondern das von den Entwässerungskanälen aufgenommene Wasser soll in einen der Bewässerungskanäle übergepumpt werden. Dieses Wasser wird also nicht endgültig aus dem Bewässerungsgebiet entfernt, sondern gelangt an anderer Stelle wieder auf bewässerte Länderein. Es handelt sich dabei um Wasser, das zwar auch noch als Süsswasser angesprochen werden kann, das aber mit dem versumpften und versalzenen Boden schon in Berührung gekommen ist, und dessen Salzgehalt dabei auf jeden Fall eine gewisse Zunahme erfahren hat. Das Projekt stellt sich also als eine zweischneidige Massnahme dar, indem zwar die Fläche unserer Abbildung 3 entwässert und dadurch deren Nutzbarkeit verbessert werden soll, zugleich aber einer anderen, etwa gleich grossen Fläche Wasser mit merklich höherem Salzgehalt zugeführt wird, wodurch Schaden entsteht, der den auf der entwässerten Fläche erzielten Nutzen teilweise, womöglich gar vollständig, kompensieren könnte.

Mit diesem Beispiel ist aber erst eine Seite unseres Meliorationsproblems berührt worden. Denn eine Melioration der versumpften und versalzenen Bewässerungsböden muss neben der Ableitung des überschüssigen Wassers vor allen Dingen auch eine Beseitigung der schädlichen Versalzung des Bodens beinhalten.

Übergehend zu diesem zweiten Problemkreis sind zunächst einige missverständliche Auffassungen zu klären. Man darf sich die hier zur Diskussion stehende schädliche Versalzung nicht so vorstellen, dass es sich dabei um Böden handelt, die lediglich durch einen ungewöhnlich erhöhten Gehalt an mehr oder weniger leicht löslichen Neutralsalzen gekennzeichnet sind. Solche Böden gibt es auch, meist Sande, die als „Salzböden" bezeichnet werden, und deren Salzgehalt leicht entfernt werden kann. Im Gegensatz zu diesen handelt es sich bei den versalzenen Bewässerrungsböden meist um lehmige bis tonige Böden, die vermöge ihres Gehalts an Tonkolloiden zu Sorptionsreaktionen mit gelösten Salzen fähig sind. Unter diesen haben die Natriumsalze hervorragende Bedeutung, weil diese im dissoziierten Zustand mit den Tonbestandteilen derart reagieren, dass das Natrium in einer von dem Natrium-Adsorptionskoeffizienten des Wassers abhängigen Menge eine als Natriumton bezeichnete Sorptionsverbindung bildet. Der Salzboden verändert sich dadurch allmählich zum Alkaliboden mit mehr oder weniger stark in den alkalischen Bereich verschobenen pH-Werten. Natriumton ist sehr stark hydratisiert, besitzt also besonders dicke Schwarmwasserhüllen, weshalb Böden mit einem beträchtlichen Gehalt an Natriumton eine sehr ungünstige Struktur aufweisen, zur Verschlämmung neigen und geringe Durchlässigkeit besitzen.

Es ist einleuchtend, dass unter solchen Umständen die Entfernung des sorbierten Natriums aus dem Boden ausserordentlich schwierig ist, und tatsächlich liegt hierin das Kernproblem der Melioration der versumpften und

versalzenen Bewässerungsböden. Von der Geländeoberfläche her, d.h. durch Bewässerung in Kombination mit einer Entwässerrung durch offene Gräben ist das Ziel nicht zu erreichen. Denn gerade in der Oberflächenschicht ist der Gehalt des Bodens an Natriumton gewöhnlich am höchsten, und infolgedessen kann das Wasser in den schlecht durchlässigen Boden kaum eindringen, sondern verursacht nur Verschlämmungen, ohne dass dabei nennenswerte Mengen Natrium aus dem Boden ausgewaschen werden können. Das Ergebnis solcher Bemühungen ist daher gewöhnlich völlig negativ, was sich dann in starken Bodenerosionen und schweren Zerstörungen an den offenen Gräben zeigt. So erklärt sich zwanglos die Tatsache, dass überall dort, wo die Melioration der versumpften und versalzenen Bewässerungsböden nur mit Hilfe offener Entwässerungsgräben betrieben worden ist, kein nachhaltiger Erfolg hat erzielt werden können.

Günstige Ergebnisse bei der Bekämpfung, sowohl der Versumpfung wie auch der Versalzungsschäden, sind nur von der Röhrendränung zu erwarten und zwar allein deshalb, weil mit Dränungen wesentlich grössere Entwässerungstiefen erreicht werden können als mit offenen Gräben. Dass für Meliorationen der hier behandelten Art eine verhältnismässig starke Absenkung des Grundwassers notwendig ist, haben zahlreiche Untersuchungen bereits erwiesen, und für die im Punjab vorliegenden Verhältnisse ist dies durch Versuche des „Irrigation and Power Research Institute" in Amritsar ebenfalls bestätigt worden. Für verschiedene Kulturen wurde festgestellt, dass ein normales Wachstum der Pflanzen erst bei einem Grundwasserstand von 1,50 m unter Gelände erwartet werden kann. Eine solche Dräntiefe sichert ausserdem eine feste Lage und anhaltende Wirkung der Dränleitungen, weil der Gehalt der versalzenen Böden an Natriumton mit zunehmender Tiefe zurückgeht, so dass die Dränrohre dann in besser strukturiertem, durchlässigerem Boden liegen, der als Filter jedenfalls besser wirkt als die stärker veränderten oberen Bodenschichten.

Es darf hier nicht unerwähnt bleiben, dass die Entfernung des sorptiv gebundenen, austauschbaren Natriums aus dem Boden nur dann möglich ist, wenn dieses gegen andere Kationen ausgetauscht wird. Praktisch kommt dafür nur Calcium in Betracht, das aber häufig in unzureichenden Mengen im Boden vorhanden ist und in solchen Fällen als Gips oder als kohlensaurer Kalk dem Boden zugeführt werden muss. Wie schnell der Austausch dann vor sich geht, zeigt ein Versuch von Chawla (Chawla, 1963), dessen Ergebnisse in Tabelle 1 wiedergegeben sind.

Der Versuch wurde in Vegetationsgefässen durchgeführt, wie sie für die sogenannte Nährlösungsmethode (Janert, 1953) entwickelt worden sind. Für den vorliegenden Zweck wurde die Versuchsansatellung nur insofern geändert, als der normalerweise siebartig gelochte Gefässboden bei der Hälfte der Gefässe durch eine dicht schliessende Platte ersetzt wurde. Auf diese Weise wurde die Dränwirkung nachgeahmt und in den Versuch einbezogen, indem „gedränte" und „ungedränte" Gefässe einander gegenübergestellt werden konnten. Die Gefässe waren mit Sommerroggen bepflanzt, der nach einer Vegetationszeit von 2 Monaten geerntet wurde. In dieser kurzen Zeit haben

Tabelle 1

Veränderunge im Gehalt einiger Böden an austauschbarem Na und Ca in % der Basenaustauschkapazität

Ursprünglicher Gehalt an austauschbarem		Gehalt nach zweimonatigem an austauschbarem Vegetationsversuch			
		Na		Ca	
Na	Ca	ungedränt	gedränt	ungedränt	gedränt
0	82,0	0	0	82,6	83,5
10	75,5	5,5	5,0	79,3	80,8
24	61,4	12,0	10,2	73,5	75,0
36	48,9	19,3	16,1	66,2	69,3
45	40,2	23,5	20,7	61,7	64,7
64	21,4	34,8	32,0	50,2	52,8
75	11,8	45,5	42,8	41,1	43,7

sich sehr erhebliche Veränderungen im Gehalt der Böden an austauschbarem Natrium und Calcium vollzogen. Vor allem ging der Gehalt an austauschbarem Natrium um mehr als die Hälfte zurück, wenn für eine ausreichende Entwässerung der Vegetationsgefässe gesorgt wurde.

Dieser Versuch zeigt mit aller Deutlichkeit, dass der Prozess der Melioration versalzener und sogar stark alkalischer (pH=9,3) Böden in kürzester Frist planmässig exakt abläuft, wenn nur 2 Voraussetzungen geschaffen werden, nämlich *ausreichende Kalkung* und gründliche *Entwässerung* des Bodens unter gleichzeitiger Weiterführung der üblichen Bewässerung.

Einfacher kann die Anweisung für eine Melioration kaum formuliert werden, zumal für eine solche, die in der Praxis als äusserst schwierig bekannt ist. Da die Kalkung des Bodens relativ einfach ist, müssen die Schwierigkeiten ausschliesslich bei der Entwässerung liegen. Dass eine Entwässerung durch offene Gräben nicht zum Erfolg führen kann, wurde schon betont. Also ist es die Dränung, deren Ausführung Schwierigkeiten bereitet, und tatsächlich hat der Verfasser gerade diese in Indien gründlich kennen zu lernen Gelegenheit gehabt.

Wir haben die ersten Versuchsdränungen auf schwer geschädigtem Gelände in der Nähe der Stadt Hissar ausgeführt und zwar mit imprägnierten und geschlitzten Bambusrohren, weil Dränrohre aus gebranntem Ton nicht kurzfristig beschafft werden konnten. Es wurde nach dem herkömmlichen Verfahren gearbeitet, und die Dränggräben von Hand ausgehoben. Dabei zeigten sich bereits grosse Schwierigkeiten, die durch mangelhafte Standfestigkeit des Bodens bedingt waren. Fortgesetzte Abbrüche und Rutschungen an den Böschungen liessen die Gräben immer breiter werden, so dass die vorgesehene Tiefe von 1,50 m nur mit grösster Mühe erreicht werden konnte. Die Bambusrohre erwiesen sich auch als ungeeignet, weil die Imprägnierung offenbar nicht ausreichend war, um das Quellen der Wandungen zu verhindern. Später sind mit gelochten Muffenrohren aus gebranntem Ton, die auf der Töpferscheibe hergestellt worden waren, gute Ergebnisse erzielt worden. Die Schwierigkeiten aber, die durch Abrutschen der Böschungen entstanden, konnten auch durch die Anfertigung spezieller Dränwerkzeuge nur gemindert, jedoch nicht beseitigt werden. Ein Dränspaten mit besonders langem Spaten-

blatt diente dazu, von einer noch mit erträglichem Arbeitsaufwand herstellbaren Sohle in 60 cm Tiefe bis zu der vorgesehenen Dräntiefe von 1,5 m durchzustechen und die Sohle auf eine kurze Strecke freizulegen, so dass ein oder zwei Dränrohre verlegt werden konnten, ehe die gefürchteten Rutschungen eintraten.

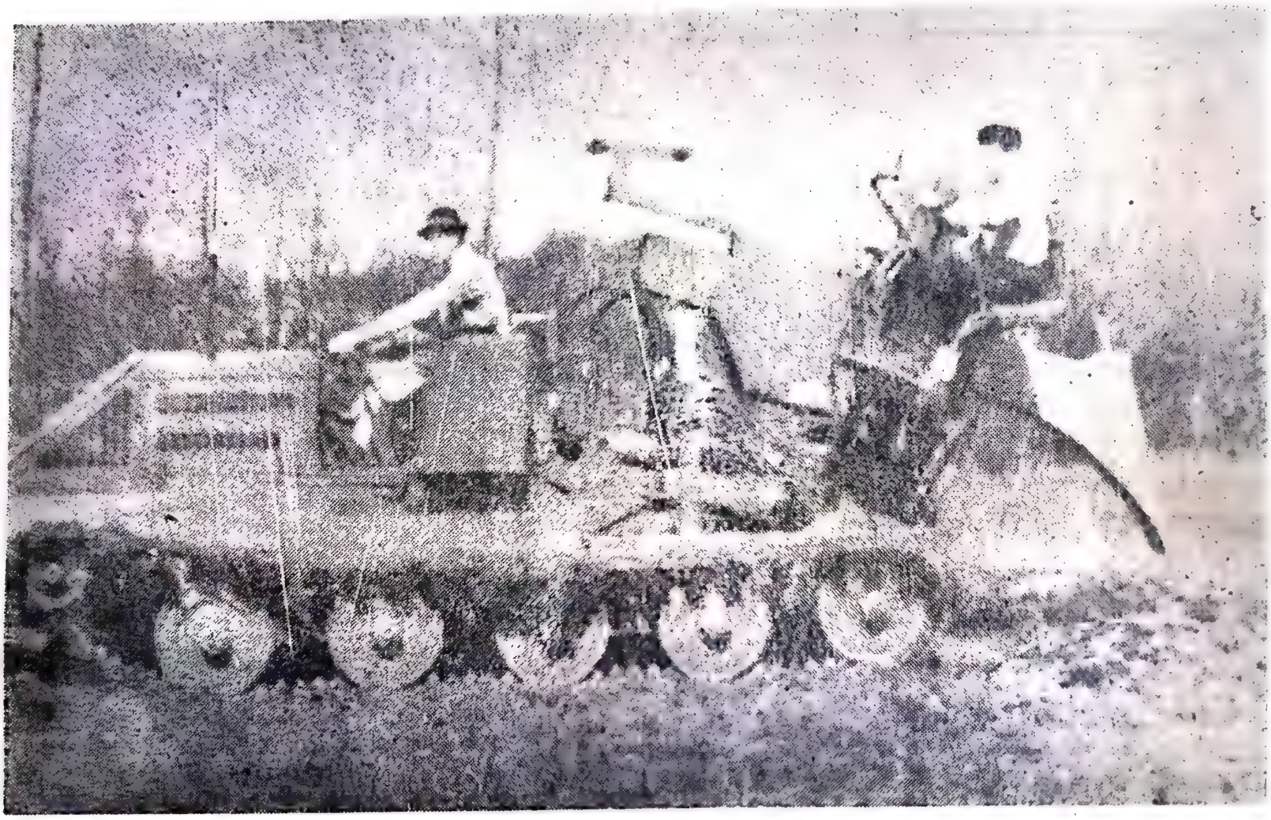

Abb. 4. Der Dränomat in Transportstellung.

Dabei musste sehr schnell gearbeitet werden, und die hierzu notwendige Kraftanstrengung war doch so erheblich, dass auch dieses Verfahren für die Routinearbeit als nicht zumutbar angesehen werden muss.

Diese praktischen Erfahrungen mit der Ausführung von Tiefdränungen in versumpften und versalzenen Bewässerungsböden liessen uns zu der Überzeugung kommen, dass diese Arbeiten künftig zweckmässiger und ausschliesslich mit Maschinen ausgeführt werden sollten. Neuerdings steht in dem von der österreichischen Firma Alpentransport GmbH in Traun bei Linz gebauten „Dränomat" eine Dränmaschine zur Verfügung, die für die geforderte Arbeit besonders geeignet erscheint. Abbildung 4 zeigt die Maschine in Transportstellung, in der das hydraulisch betätigte, hobelartige Dränwerkzeug ausgefahren und so geschwenkt ist, dass es gut zu erkennen ist. Das von einem 90 PS Stayr-Dieselmotor angetriebene Fahrwerk läuft auf 5 Rollenpaaren und gibt der Maschine eine Arbeitsgeschwindigkeit von 360—600 m/h bei einem Bodendruck von nur 0,17 kg/cm² und einer Arbeitstiefe von maximal 1,50 m. Mit der Maschine können Kunststoff-Dränstränge von 3,5 cm und solche von 6 cm Lichtweite, sowie wahlweise auch Dränrohre aus gebranntem Ton von 5 cm oder 8 cm Lichtweite verlegt werden.

Die Möglichkeit der Verarbeitung von Dränrohren aus gebranntem Ton ist vor allem für solche Länder vorgesehen, die nicht über eine genügend leistungsfähige Kunststoffindustrie verfügen und daher das Material importieren müssten. Gegebenenfalls können die Dränrohre mit kleinen, aus handelsüblichen Fleischmaschinen gefertigten und durch Göpel angetriebenen Drän-

Abb. 5. Der Dränomat bei der Dränarbeit.

rohrpressen an der Baustelle aus örtlich vorhandenem Lehm hergestellt werden.

An dem Dränhobel kann ein Füllschacht angebracht werden, der die Aufschüttung von Filtermaterial auf den Dränstrang während dessen Verlegung ermöglicht.

Diese neue Dränmaschine ist speziell für die Dränung versumpfter und versalzener Bewässerungsböden ausgelegt worden und zwar sowohl bezüglich der erforderlichen Dräntiefe, wie auch hinsichtlich ihres Arbeitsprinzips. Denn der Dränomat bringt die Dränstränge in den Boden ohne dass der Aushub von Drängräben erforderlich ist. Vielmehr gelangen die Dränrohre durch den Dränhobel hindurch in ihre vorgeschriebene Lage im Boden, der zu diesem Zweck nur aufgebrochen wird und nach dem Passieren des Dränhobels den verlegten Dränstrang automatisch wieder zudeckt. Bei dieser Arbeitsweise entfallen demnach alle zuvor geschilderten, mit dem Aushub von Drängräben verbundenen Schwierigkeiten.

Dank der Entwicklung dieser Dränmaschine kann die letzte und zugleich bedeutendste Schwierigkeit, die der Melioration der versumpften und

versalzenen Bewässerungsböden der ariden Gebiete bisher entgegenstanden, als durchaus überwindbar angesehen werden. Dadurch dürfte die — im Weltmassstab gesehen — grösste vor uns stehende Meliorationsaufgabe eine wesentliche Förderung erfahren. Um die Erschliessung der ariden von der Versalzungsgefahr bedrohten Gebiete, die ein Viertel aller Böden der ganzen Welt umfassen, wird seit Jahrhunderten ein zäher Kampf geführt. Diesen Kampf, der sich noch in seinem Anfangsstadium befindet, wird die Menschheit nur durch die Entwicklung und den Einsatz modernster technischer Hilfsmittel für sich gewinnen können.

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ZUSAMMENFASSUNG

In den Gebieten mit versumpften und versalzenen Böden ist leider nur die Entwässerung durch offene Gräben bekannt und gebräuchlich, woraus sich ohne weiteres der Misserfolg der bisherigen Bemühungen um die Rekultivierung dieser Böden erklärt.

Allein mit Hilfe der modernen, vollmechanischen Dräntechnik ist es möglich, die versumpften und versalzenen Böden mit Sicherheit zu rekultivieren, weil dabei die Dränrohre mit Hilfe eines hobelartigen Werkzeuges in den Boden eingeführt werden, ohne dass dazu Gräben ausgehoben werden müssen. Dieses neue Dränverfahren ist bisher nur unter Verarbeitung von Plastikmaterial angewandt worden. Neuerdings können aber mit dem „Dränomat" auch Dränrohre aus gebranntem Ton vollmechanisch verlegt werden, die an der Baustelle aus heimischem Material mit eigens zu diesem Zweck entwickelten, einfachen, kleinen Dränrohrpressen hergestellt werden können.

SUMMARY

In the areas of waterlogged and salted soils, only surface drainage through open ditches is generally known, and this fully accounts for the failure of all efforts so far made in the reclamation of these soils.

Exclusively by the application of modern, fully mechanized drainage techniques, it becomes possible to safely drain the waterlogged and salted soils, because this is now being done by instruments shaped like a grooving plane, which are used to install the drain pipes without digging operations. For this new drainage technique only plastic material has so far been used. However, recently the new machine "Drainomat", has been devised so that either plastic pipes or drain tiles can be installed, as required. These drain tiles can be manufactured on the site, with local raw material in a simple way by using drain tile presses built for this purpose.

RÉSUMÉ

Dans les régions de terrains marécageux et imprégnés de sels, on ne connaît et pratique que le drainage par fossés ouverts. Ce n'est donc pas étonnant que les efforts entrepris pour la récupération de tels terrains n'ont pas encore pu aboutir. Ce ne sera que l'utilisation de la technique de drainage moderne, pleinement mécanisée, qui rendra possible la récupération pour la culture de terrains marécageux et imprégnés de sels, parce qu'avec cette technique on peut introduire

les tuyaux de drainage dans le sol moyennant un appareil en forme de rabot, sans qu'il soit nécessaire de creuser. On s'est servi de ce procédé, jusqu'à maintenant, en utilisant seulement des matières plastiques. Mais dès maintenant il est aussi possible de poser, de cette manière pleinement mécanisée, des tuyaux de drainage en argile cuite, avec ce "drainomat". On peut fabriquer ces tuyaux sur le lieu du chantier même, avec des matières disponibles sur place, en se servant pour cette fabrication de presses simples, qui ont été spécialement construites à cet effet.

DISCUSSION

M. L. DEWAN (FAO). What is the cost of drainage with the machine and what is the rate of drainage per time unit which has been, I presume, utilized in the East Punjab part of India?

H. JANERT. The drainage-machine has not been used in India, and therefore nothing can be said about the economical side of its work. The rate of work per unit time has been stated to be 600 m/hour.

K. VAN DER MEER (Netherlands). It is known from some tile drainage experiment field on rather impermeable soils, that the trench, filled with loose earth, is very susceptible to the attack of superficial flowing water, after a heavy rainshower. The trench fill is washed away and the trench is a starting point of gully erosion.

Does your system present such problems, or are these problems minor compared to other methods of execution?

H. JANERT. If heavy erosions are to be anticipated, the new drainage system offers the opportunity to cover the drains through the "Füllschacht" with gravel or other local material which may prevent erosion of the soil and of the drain trench.

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REGULARITIES OF SOIL FORMATION AND MELIORATION OF CONTINENTAL DELTAS

V. M. BOROVSKI, M. A. POGREBINSKI [1]

Delta regions of the rivers are extremely varied. Delta structure depends on the characteristics of geographical conditions and how long the process of delta formation had lasted, i.e. the age of the delta.

Samoilov (1952) summarized and compared the data of his studies on mouths of the world's sixty longest rivers. He divided these rivers into four genetic types which at the same time are age stages. In the process of delta formation and while original ruggedness of the earth surface had been filled with alluvium, these stages were following one after another.

The last (the fourth) genetic type of the most developed delta was named by Samoilov a "large-island" type. Its surface is "a level land with inclination towards the sea with large honeycomb-like relief of depressions between the branch channels" (Samoilov, 1952). The sea has no effect on the major part of the surface of such deltas. Very often they occupy large land areas and the formation of their relief, soils, and accumulation of alluvium are mainly regulated by subaerial processes. In this respect, they are much different from other earlier stages of delta formation where a great part is played by the subaqueous foredeltaic processes on the seaside of the delta.

Samoilov regards the mouths of the Kuban, the Nile, the Danube, the Amu-Dar'ya, the Syr- Dar'ya, the Terek, the Colorado, the Indu, the Mekong, the Irrawaddy, the Volga, the Don, the Dnieper, the Orinocco, the Neman, the Wisla, and the Parva rivers as the above mentioned "large-island" type continental deltas.

It is very characteristic of the mentioned deltaic regions to form complex systems of spreading in a fanlike pattern and then interflowing again in meandering streams.

As a rule, along stream channels accumulative natural levees are formed. They are composed of layered alluvium of light-textured granulometric composition. Much thinner alluvium beds are deposited between stream channels. Here the accumulative process is much slower, these areas do not grow as fast as bank levees, thus forming interchannel deltaic depressions.

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The size of the levees is in proportion with the size and age of stream channel activities. As a result of continuous extinction and appearance of new streams of the most varied dimensions, between the main arms of the delta, which are banked with thick levees, wide depressions are formed with intricate patterns of bandlike dividing elevations of the second order in the place of the small extinct streams and flat lowlands between them.

These characteristics of delta formation may somewhat vary in rivers with different geological conditions. However, the data on hand lead us to believe that regularities of delta formation are of a very important extremely widespread general nature.

Bank levees of the Volga deltaic streams are composed of sandy and sandy loam rocks. The island plains between the streams are composed of various loams. Coastal alluvial soil depressions are composed of heavy loams and clays enriched with colloids, which is of a great importance for soil formation (Kovda, 1951).

In the large ancient Bakanass delta and the present delta of the Ili river in the Southern Pribalkhash region, the bank levees of the deltaic streams, composed of sandy and sandy loam deposits, form a very complex pattern of deltaic divides, the depressions between these divides are composed of a finer texture. The difference in the lithologo-morphological characteristics and hydrological regime of the basic elements of the Ili-delta has determinative significance for formation of the soil surface Pogrebinski Borovsky et al., 1963).

Studies of the right bank area of the Amu-Dar'ya delta proved that activities of channels of the most various sizes comprise a factor of relief formation and lithological differentiation of the alluvium; bank levees are composed of lighter textures while granulometric composition of deposits between them is much heavier.

Statistical data have proved that 4/5 of delta surfaces are composed of two types of deposits: 1) fluvial (sand and sandy loams in the bank levees), and 2) lacustrine (heavy loams and clays in the flooded depressions) And only 1/5 of the surfaces is comprised of transitional, i.e. intermediate type (Kalashnikov et al., 1956).

The detailed study of the left bank of the Amu-Dar'ya delta registered two basic types of the surfaces: 1. a net of closed depressions up to 1—3 and sometimes up to 5 meters deep, composed of heavy-textured alluvium deposits, and 2. a complex system of intersecting fluvial and near-channel deposits of light-textured granulometric composition (Vailert et al., 1961).

Even in the upper regions of the river deltas, which according to their genetic type belong to an earlier stage of development, the same process of unity of litho-morphogeny has been found. In the Missisippi delta, the bank levees are formed of light—textured material, while honeycomb-like depressions between them are composed of clay deposits (Eichberger, 1961).

Foredeltaic deposits play an important part in littoral regions. In the areas far removed from the seashore, these deposits, as a rule, undergo considerable changes owing to activities of the swinging meandering channels, which even at a very small gradient accomplish great work by the way of the lateral erosion.

Instability of a channel, bank, slides, continuous stream migrations are characteristic of delta regions of every long river. As a result of this processing, the deltaic deposits, except the narrow littoral area, have peculiar traits of alluvium, i.e. binary structure or general underlying of sediments of different facies with coarser grained stream chanel alluvium. Sandy underlying has been registered by many research workers in the Amu-Dar'ya, the Syr-Dar'ya, the Ili, the Volga and many other river deltas.

Thus, the relief, the alluvium structure and the hydrologic regime in a delta are closely genetically interconnected and comprise the factors which determine the nature of vegetative cover and mantle development.

Table 1 shows the schematic comparison of the bank levee landscapes with flooded areas of honeycomb-like interchannel depressions in the Syr-Dar'ya delta.

Delta areas are characterized by considerable variability of conditions and by intense dynamics of processes.

In conformity with development stages of deltas a complex course of evolution takes place in the soil of bank levees.

During first stages in the Syr-Dar'ya delta, formation when the levee is still small and is slightly raised above the water level meadow-swampy soils are formed. They are overgrown with reeds and willows. The appearance of dense vegetation accelerates accumulation of sediments considerably, which means that the rate of high water flow greatly decreases when passing through dense vegetation, and suspended material settles between the plant stalks in great quantities.

Fully developed bank levees are rising 1.5—3 meters above the river level. Ground waters are closely connected dynamically with river waters. Their type of regime is hydrological. Under hydrostatic pressure from the river they are slowly flowing in the direction opposite to channels and are weakly mineralized, the depth of their bedding may be from one to three meters.

The soils are well moistened from below the whole year round. Capillary flow reaches the surface. All this secures development of thick moisture-loving vegetation comprising motley grass and brushwood species under which alluvial meadow soils are formed. They have a humus-accumulative horizon from 15 to 40 cm in thickness, with humus contents from one to four per cent. Bedded structure consists only of light textured interlayers. From the surface they are strongly salinized with water soluble salts. The cross section is relatively saltless. Rate of their salinization greatly varies depending on the season. During dry years when bank levees are not flooded, their salinization gradually increases. While during wet years, high water flooding levees dissolves salts and by means of the surface as well as of filtrating and subsurface runoff, carries them out into honeycomb-like interchannel depressions.

Table 1

Characteristics of Main Elements of the Syr-Dar'ya Delta Landscape

Relief elements	Alluvium granulometric composition	Nature of high water inundation	Ground water	Vegetation	Soil
Levees of the main channel and longest active streams	Light-textured	Short-lived inundation during high floods	Fresh, circulating water of river regime at a depth of 1—3 meters	Brush-wood and meadows	Alluvial meadow and tugaic soils
Levees of small extinct streams	Light-textured	Not inundated or inundated very seldom for a short period during catastrophic high floods	Brackish, with narrow local withdrawal at a depth of 3—5 meters of the hydrologic and irrigation regime	Motley grass and weeds	Alluvial meadow soils with various degrees of salinity
			Strongly mineralized, stagnant with circular backup water from inundated depressions at a depth of 2—5 m, of the hydrologic regime	Fat Russian thistles	Solonchaks
Lowlands of interchannel depressions	Heavy textured	Continuous inundation with formation of stagnant basins	Fresh, brackish stagnant, of alluvial and irrigation regime at a depth of 0—7 meters	Reed banks	Swampy and meadow-swampy soils

As may be seen, the main factor which determines the possibility and term of alluvial meadow soil existence is the hydrological regime. When it changes, the soils of the bank levees undergo transformation. When a stream channel shoals and there is no water recharge, the soils of the bank levees in the flooded delta regions are inundated from the adjacent flooded depressions.

The ground water stagnates and advantageous elements of the relief become foci of water evaporation and salinization. Alluvial meadow soils become puffed solonchaks which contain great quantities of salts in the soil and ground water. Hydrophytic plants dry out and a few halophytes appear instead. It has been calculated that in the Syr-Dar'ya delta solonchaks occupy 17.3 per cent of the whole surface, but there is concentrated 70 per cent of the whole salt reserves of the delta.

During the first period of solonchak formation, humus reserves which had accumulated in the former stage, are quickly reduced by micro-organisms not to be restored again.

In the honeycomb-like interchannel depressions natural conditions are quite different. Here high water streams carry only very fine suspended material and deposit heavy clay alluvium. The flood is of a persistent nature, and in deep depressions shallow lakes are formed, some of them may exist for a number of years. Substratum is saturated with water and overgrown with reeds, which produce great quantities of organic matter. Swampy soils are formed with well expressed anaerobic processes, or gleyization. In deoxidizing medium, the transformation of organic matter is of an anaerobic type, small turf beds are formed on the surface. Large quantities of raw-humified organic matter contribute to the rich development of sulfate reducing micro-organisms which use it as an energy matter, reducing sulfates and producing hydrogen sulfide. Sulfides with polyvalent metals (mostly iron) form coal-black gouges and interlayers in the soil. Cyclic hydrologic river regime causes very irregular inundations. During dry years they may be very insignificant or absent. The transpirative nature of reed vegetative association contributes to lowering of ground water level on the clay soils with small coefficient of water yield to the depth of three to five meters during one vegetative season. Thus, ground water in conformity with hydrological intermittency at times emerges on the surface by means of overlapping infiltrating fresh high water, at others, submerges to the depth of over five meters as a result of discharge for transpiration and partly for diffluence from the flooded depressions. As a result, the swampy anaerobic process is periodically replaced by accentuated aeration (when both inundation and lowering of ground water level are absent). Under such conditions, when organic matter is decomposed, many soluble products are formed. The products inwash deep into soil, and its humic profile stretches, so that organic matter gauges and runs can be traced to the depth of one or even two meters.

Salinization of swampy soils is usually insignificant, for conditions under which progressive salt accumulation either in soils or in ground waters takes place, are lacking.

Naturally, besides above mentioned soils in deltas there are others. Their position, however, is intermediate.

Soil-geochemical nature of deltas, i.e. types of soil and ground water salinization are determined by geographical position of the delta and entire river basin, by its geological structure, history of development and age.

PRINCIPLES OF ECONOMIC UTILIZATION AND MELIORATION OF DELTAIC SOILS

Wide variety of nature of deltaic soils determines different methods of their development for irrigation.

Alluvial swampy soils on the elevated elements of the relief are in need of some leaching, so as to wash out the excessive salts from the upper horizon. It is recommended to use these soils for cultures which need soils with

good aeration, such as corn, vegetables, melons, industrial and orchard crops. These soils have a complex microrelief and short humus cross section which is not advantageous for layouts with deep shears, otherwise special measures must be undertaken for the liquidation of disordered sowing on the exposed low productive sand spots. The most advantageous would be sprinkling irrigation in small but frequent batches. Irrigation control helps to maintain the conditions and high soil productivity at a low cost.

These regions are utilized for irrigation channels having the best commanding positions. Measures, such as colmatage, revetment, piping should be taken to control water losses from the channels by percolation. For cultivation of solonchaks, through leaching of salts should be conducted together with draining of saline ground and wash water. Drainage water, as a rule, cannot be liquidated by gravity flow, it must be pumped out. Secondary utilization of drainage water in the first two or three years does not pay.

It should be removed from the irrigated territory. Leached solonchaks may be utilized the same as alluvial meadow soils, however great quantities meadow of organic fertilizer should be used.

Swampy soils of the interchannel depressions are mainly flat lands and there is no need of complicated levelling work. Ocasionally there may be some rare spots where deep shears and considerable soil shifting be undertaken. It would be most advantageous to utilize these soils for the crops which need flooding, creating a layer of water on the field (paddy), because losses by percolation and diffluence are here the least, and cannot harm adjacent lands, while irrigation of these flat lands is the cheapest. Water balance of these soils must be controlled by means of collector draining network, which should be thotroughly reinforced, so as to prevent water losses along the collectors fields are inundated. The tendency of these soils to be bogged up and accumulate when reduced compounds is very strong, thus rice one-crop system here is not very effective. These fields must be periodically dehumidified and used for crops which do not require much watering. Here legumes (alfalfa) would pay the best.

Arid zone delta soils are in need of nitrogenous fertilizers and in a lesser degree, of phosphorous. Nitrogenous fertilizer composition of the channel levee, alluvial meadow soils and interchannel depression, meadow swampy flat lands variy. For the alluvial meadow soils with good aeration and periodical irrigation, salpeter is used. For flatland, meadow-swampy soils with anaerobic process in the inundated paddies, ammoniacals and nitrogenous fertilizers (ammonium sulphate) should be used. Standards for fertilizers are determined by balance calculations depending on the fertilizer requirement of the crop, its expected yield and conditions of nutrients in the soil. Especially great demand for fertilizers in the irrigable deltaic soils is felt during the first few stages of plant development.

If the river runoff is not under control, the fields must be protected from inundation.

Thus, owing to the single process in lithomorphogenesis and soil formation, the main factor for which is hydrologic regime, the contour of the channel

levees and interchannel honeycomb-like depressions, determine the placement of the crops and the main irrigation network on their territories.

Interchannel levee pattern determines the most advantageous placement of the water supplying irrigation network, while the axes of interchannel honeycomb-like depressions determine the layout of collector lock-weir net.

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SUMMARY

Simultaneous processes of accumulative relief formation, of alluvium facies differentiation and soil formation take place in delta regions. This processes are controlled by the hydrological regime of the territory and the natural law of transporting and sedimentation of loose matter with the flow water. As a result, channel bank levees, consisting of light deposits and alluvium meadow soils, are formed along river beds, determined by the nearest fresh ground water of the river regime. Between river beds honeycomb-like interchannel depressions of bog soils of a heavy granulometric composition and stagnant ground water are formed.

Great genetic differences in these natural landscapes determine the necessity of quite different methods of approach for their economical reclamation and selection of crops for cultivation. The described regularities are observed in many river areas and should be considered when conducting agricultural work in them.

RÉSUMÉ

Dans les régions des deltas ont lieu des processus simultanés de formation du relief par accumulation, de différentiation de facies des alluvions et de formation du sol. Ces processus sont réglés par le régime hydrologique et par la loi naturelle du transport et de la sédimentation de la matière meuble par écoulement d'eau, Comme résultat, le long des lits de rivières se forment des bourelets en forme de canal, consistant en dépôts légers et des sols de prairies alluviales, déterminés par l'eau douce phréatique la plus proche du régime de l'eau de rivière.

Entre les lits de rivières se forment parmi les canaux des dépressions de sols tourbeux, à structure alvéolaire, d'une composition granulométrique lourde et à eau phréatique stagnante. De grandes différences génétiques dans ces paysages naturels imposent la nécessité de méthode de recherches différentes pour leur amélioration économique et l'assortiment des cultures. Les régularités décrites sont observées dans les zones de maintes rivières et devraient être prises en considération lorsqu'on y entreprend des travaux agricoles.

ZUSAMMENFASSUNG

In Delta-Gegenden finden gleichzeitig Vorgänge akkumulativer Reliefbildung, Differenzierung der Alluvionsfazies und Bodenbildung statt. Diese Vorgänge werden durch den Gebiets-Wasserhaushalt und das natürliche Gesetz der Beförderung und Absetzung lockeren Materials durch Strömungswasser geregelt. Als Folge bilden sich längs der Flussbetten Kanalgestade, die aus leichten Ablagerungen bestehen, und alluviale Aueböden, bedingt durch das nächstliegende Süssgrundwasser des Flusswasserhaushaltes.

Zwischen den Flussbetten bilden sich honigwabenartige Zwischenkanal-Bodensenkungen von Moorböden mit schwerer Korngrössenzusammensetzung und stehendem Grundwasser. Grosse genetische Unterschiede in diesen natürlichen Landschaften bestimmen die Notwendigkeit sehr verschiedener Untersuchungsmethoden für ihre wirtschaftliche Melioration und die Kulturpflanzenauswahl. Die beschriebenen Regelmässigkeiten werden in manchen Flussgebieten beobachtet und müssten in Betracht gezogen werden, wenn landwirtschaftliche Arbeiten in diesen Landflächen unternommen werden.

DISCUSSION

J. W. HOLMES (Australia). Evidently, from what Professor Borovsky has told us, there is a lot of seepage from the Sîr-Darya River in its levee-flow regime. Could Professor Borovsky tell us if he has been able to devise some technique for measuring seepage flow from rivers flowing on the levee, in an arid delta region?

V. M. BOROVSKY (U.S.S.R.). In the antical delta of the Sîr-Daria river, in the years of abundant moisture, the flooding comprises enormous amounts of water, approximately 16 cub km^3 annualy. The whole of the water is spent, sooner or later, in evapotranspiration because the ground-water basin having no runoff.

RECLAMATION AND USE OF MARINE SALINE SOILS

A. J. DA SILVA TEIXEIRA, A. SALEMA VEIGUINHA,
A.J. DE SOUSA E ALVIM[1]

1. THE PROBLEM

In Portugal there are four main areas of about 22,700 hectares of marine saline soils, named "sapais".

With good fertility and a topography favourable to mechanization, these soils are to be found in high population density areas and close to important consumption centres.

Their reclamation faces the generally known difficulties, added to a climate characterized by a long hot dry season.

The Portuguese 2nd Development Plan, now on the way, recognizing the importance of reclaiming these soils, has provided the facilities for carrying out their necessary basic studies.

2. THE SOIL RECONNAISSANCE

The general reconnaissance of the marine saline soils made during the soil survey of Portugal (scale 1:50,000) and other soil studies, disclosed the presence of soils of variable salinity, acidity and texture, with or without carbonates.

Generally, the Portuguese "sapais" are found in estuaries or lagoons separated from the sea by sandy strips. Their nature is determined by local conditions such as tides, flow volume of streams, transported sediments, salinity, etc.

With a variable depth, sometimes greater than 3 m, they generally have a dominance of clay and silt (90 per cent or higher), and may present layers relatively high in organic matter, sulphur compounds (acid sulphate

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soils), or sea-shells, all of them laying on sands. Clay mineralogical analyses have shown a dominance of illite, the presence of kaolinite and some quartz (Anonymous, 1955).

3. EXPERIMENTAL FIELDS AND PROGRAMMES

Based on data of the general soil reconnaissance, two experimental fields were set up, one for dry farming experiments, in Faro, and the other for irrigated crops, mainly rice, in the Sado's valley. The installation of two other experimental fields is almost complete (Tavira and Alvor).

Detailed soil maps were made and analytical methods for saline soils studied and applied to the physical and chemical characterization of the soil units.

Analytical data for some soil units of the experimental field of Faro (Alvim and Veiguinha, 1962) and of Sado are shown in the table 1. In the Faro's experimental field, protected from the sea forty years ago, five soil units were mapped: two with surface layers having high calcium carbonate content and neutral or slightly alcaline reaction; and three having acid reaction and, at variable depth, extremely acid layers. Whatever the soil units, there were, at the surface, nonsaline alternating with moderately saline areas (ECe variable between 4 and 10 mmhos/cm). As a rule, the salinity increased with depth being very high in the deeper layers.

As to the Sado's experimental field, the soil is clayey down to 1 m, sometimes with organic matter accumulations, moderate to high salinity at the surface (ECe variable between 6 and 20 mmhos/cm), and very high in deeper layers. There is no calcium carbonate, and the base exchange complex is dominated by magnesium and sodium ions. The low pH of some air-dried soil samples suggests the presence of potential cat clay areas. Some soil samples from the Tavira's experimental field also showed the presence of potentially acid cat clay areas. As the knowledge of their distribution before installing the drainage system is of great practical value, soil samples were taken, every 20 cm, by boring down to 1 m depth and following a close network of boreholes. A soil pH map was thus drawn and an effort is being made to get correlations between the plotted areas and other soil and vegetation characteristics for future use in the surveying of these soils. At the same time, a quick test is being searched to detect in the field the potentially acid non drained cat clay areas.

In the experimental fields of Faro and Sado trials were made using calcium carbonate, calcium oxide, and calcium sulphate as amendments, and a crop adaptation study was carried out together with periodic soil analyses of the experimental plots.

In the Tavira's experimental field programme a sand mulch trial is envisaged, hoping to favour in that way the elimination of excessive sodium chloride from the soil, the saving of water and the shortening of the crop's life cycle.

Profile № Depth (cm)	7			29		
	0—29	29—62	62—100	0—15	15—35	35-
1. Mechanical analysis						
coarse sand %	0.1	1.9	18.7	1.3	0.1	0
Fine sand %	8.7	33.0	42.0	8.7	6.1	18
Silt %	36.2	25.6	30.2	40.5	35.4	31
Clay %	55.0	39.5	9.1	49.5	58.4	49
2. N %	0.16	0.12	0.21	0.18	0.10	0
3. C %	1.49	0.66	1.92	2.20	1.04	1
4. pH	6.0	6.4	2.6	7.9	6.7	7
5. SP (1)	64.8	61.0	53.5	86.6	68.8	65
6. EC (2)	2.4	6.9	17.8	3.6	13.2	18
7. Saturation extract						
a) cations me/l.						
Ca^{++}	3.25	25.00	7.50	7.30	17.30	53
Mg^{++}	11.11	18.03	9.16	9.00	41.56	49
K^{+}	0.77	1.14	0	0.92	2.47	3
Na^{+}	13.88	30.98	125.04	22.17	100.0	115
b) Anions me/l.						
Cl^{-}	23.7	—	147.3	116.1	174.2	234
SO_4^{--}	19.33	43.30	—	18.93	21.40	52
CO_3^{--}	0	0	0	0	0	0
HCO_3^{-}	0	0	0	2.80	0.68	1
8. Exchangeable bases me/100 g						
Ca^{++}	8.49	—	2.80	—	—	
Mg^{++}	4.18	—	5.21	—	—	
K^{+}	2.25	1.33	0.06	2.32	2.33	2
Na^{+}	2.10	0.51	4.81	2.68	4.22	8

(1) Saturation percentage. Methodes as described by Richards, L. A. (ed.) 1954 Diagnosis and Improvemer

(2) Electrical conductivity of saturation extract.

29			1			64			
5—35	35—65	65—85	0—27	27—55	55—100	0—22	22—40	40—65	65—100
0.1	0.3	4.3	1.5	0.2	0.9	0.7	0.2	0.1	0.1
6.1	18.0	41.4	17.2	8.6	26.0	9.2	7.1	17.6	64.4
35.4	31.9	21.8	46.7	36.9	41.7	29.8	32.9	32.5	25.5
58.4	49.8	32.5	34.6	54.3	31.4	60.3	59.8	49.8	10.0
0.10	0.18	0.07	0.15	0.20	0.22	0.15	0.12	0.14	0.17
1.04	1.26	1.45	0.75	1.59	1.93	1.31	0.95	1.95	2.80
6.7	7.3	7.9	6.2	3.2	2.9	5.8	4.3	3.3	2.8
58.8	65.3	62.1	61.5	76.0	65.2	60.0	76.8	64.8	75.2
13.2	18.0	12.2	2.7	10.4	30.6	4.6	13.9	13.9	18.1
17.30	53.0	53.0	1.25	10.50	10.80	2.66	4.03	5.40	5.70
41.56	49.31	31.40	6.50	4.68	65.80	3.33	1.04	28.55	55.86
2.47	3.06	2.25	0.65	1.58	4.14	0.75	0.73	1.08	0
00.0	115.31	81.64	9.43	66.18	319.02	17.17	20.57	108.95	32.71
74.2	234.2	130.1	26.8	98.2	260.2	41.5	—	164.2	58.0
21.40	52.70	57.10	11.74	135.52	—	9.85	90.05	122.80	249.90
0	0	0	0	0	0	0	0	0	0
0.68	1.13	1.17	0	0	0	0	—	0	0
—	—	—	8.22	7.00	5.20	6.54	1.19	2.95	1.07
—	—	—	4.30	3.90	6.91	6.80	4.22	3.95	4.00
2.33	2.70	1.26	1.76	1.08	0.13	1.56	1.34	0.83	0.03
4.22	8.97	3.83	1.88	4.77	9.70	2.37	1.72	5.74	13.54

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Sado's Experimental

	220			1			2			
—100	0—10	10—30	30—100	0—40	40—55	55—100	0—20	20—32	23—72	0—15
).1	1.6	1.6	—	0.2	0.1	0.1	0.1	0.02	1.0	1.3
!.4	10.1	9.6	—	2.0	—	1.5	2.1	0.08	2.2	1.9
;.5	34.9	30.4	50.0	26.8	39.5	36.8	26.6	30.6	32.7	28.3
).0	53.4	58.4	20.6	71.0	46.9	61.6	71.2	69.3	64.2	68.5
).17	0.17	0.17	0.13	—	—	—	—	—	—	—
:.80	1.79	1.37	2.58	—	—	—	—	—	—	—
:.8	4.0	3.6	3.1	6.0	5.5	5.6	5.6	5.7	7.1	3.8
.2	49.5	74.1	41.9	103.	183.	115.7	107.6	116.8	97.6	92.9
.1	4.4	5.5	25.9	6.2	25.0	22.0	22.0	50.0	35.0	17.4
.70	5.55	0.81	6.20	2.25	8.55	5.65	—	—	—	4.25
.86	1.21	1.08	114.55	11.2	—	35.8	—	—	—	38.2
	1.01	0.94	0.23	1.73	4.97	4.97	7.63	16.38	9.06	3.79
.71	16.56	26.58	117.56	48.1	162.3	132.96	166.53	475.42	249.8	64.10
0	24.2	37.0	180.0	46.9	180.7	156.3	200.2	600.8	298.0	61.60
90	5.14	—	542.70	24.84	81.91	31.55	86.36	203.06	135.8	86.53
	0	0	0	0	0	0	0	0	0	0
	0	0	0	4.5	13.5	13.5	15.8	4.5	0.0	0
07	1.85	0.84	4.50	—	—	—	—	—	—	—
00	2.14	1.42	3.60	—	—	—	—	—	—	—
03	0.85	1.04	0.19	—	—	—	—	—	—	—
54	1.88	1.73	13.06	—	—	—	—	—	—	—

Sado's Experimental Field

2			8			X			
—20	20—32	23—72	0—15	15—40	40—95	0—40	40—65	65—90	90—130
0.1	0.02	1.0	1.3	0.3	0.2	—	—	—	—
2.1	0.08	2.2	1.9	1.3	2.2	—	—	—	—
26.6	30.6	32.7	28.3	24.6	38.3	—	—	—	—
71.2	69.3	64.2	68.5	73.8	59.3	—	—	—	—
—	—	—	—	—	—	0.19	0.22	0.14	0.14
—	—	—	—	—	—	1.85	3.17	1.68	1.53
5.6	5.7	7.1	3.8	3.4	5.8	6.7	5.1	6.5	5.9
07.6	116.8	97.6	92.9	104.4	102.9	101.4	105.0	117.2	111.6
22.0	50.0	35.0	17.4	17.7	42.9	8.7	32.0	41.0	45.0
—	—	—	4.25	4.00	9.75	2.87	13.0	10.25	11.25
—	—	—	38.2	—	152.9	20.55	124.94	124.94	158.15
7.63	16.38	9.06	3.79	4.80	13.90	8.8	13.5	11.1	11.9
66.53	475.42	249.8	64.10	113.0	356.8	90.0	335.0	402.0	500.0
200.2	600.8	298.0	61.60	83.0	371.3	95.16	307.44	400.16	502.64
86.36	203.06	135.8	86.53	104.10	151.74	38.6	154.4	150.8	173.1
0	0	0	0	0	0	0	0	0	0
15.8	4.5	0.0	0	11.3	15.8	1.25	1.00	1.50	2.50
—	—	—	—	—	—	7.76	6.31	5.14	4.66
—	—	—	—	—	—	15.22	19.03	17.76	12.95
—	—	—	—	—	—	2.34	5.58	5.20	6.42
—	—	—	—	—	—	10.88	7.45	6.64	8.78

4. SOME RESULTS

a, *Possibility of reclaiming the Portuguese marine saline soils without irrigation*

The Faro's experimental field has been used during several years for rain grown crops and the results confirm the initial hypothesis that it is possible to base the reclamation of these soils on rainfall alone (423 mm, annual average). The hydrological balance estimated by the Thornthwaite-Mather's method for an available water capacity of 150 mm and average rain and temperature data for thirty years, showed however a different picture. As a matter of fact there is a water deficit from April to October and no month on the whole year with a water surplus; this would imply therefore the use of irrigation for salt removing from the layers explored by the roots. In some years rainfall, higher than the normal, will apparently suffice to reduce the salts in excess. In 1959 and 1960, for instance, water surpluses were registered in March and February-March, respectively, with a consequent lowering of the salinity levels of the Faro's experimental field (Alvim and Veiguinha, 1962).

b. *Efficiency of the lime treatment in reclaiming the cat clay soils*

The application of CaO (10 t/ha) has been very successful in the reclamation of marine acid clay soils. Crops, such as barley, which could not be grown, before the amendment, showed good initial response to lime application to the 25 cm surface layer. However, in the final stages of the life cycle, the barley showed poor growth probably due to rooting difficulties in the deeper acid layers. A recent trial to test this hypothesis showed that lime plowed under to a depth of 50 cm greatly improved the growing of barley.

c. *Response of some crops to acidity and salinity of the marine saline soils*

In the Faro's experimental field the following rain-grown crops were tried: barley, wheat, oats, rye, maize, sorghum, broad beans, beet, tomato, *Lolium multiflorum*, *Melilotus segetalis*, *Vicia atropurpurea*, *Lathyrus ochrus* and *L. clymenum*. Almost all the crops, especially *Melilotus segetalis*, barley and beet, were very sensitive to cat clay acidity; *Lolium multiflorum*, rye and oats showed higher resistance to these conditions.

All the crops tried on soils with some calcium carbonate present, showed good growth; the same statement applies to the acid soils when well limed. Productions as high as 2,700 kg/ha for wheat, 1,600 kg/ha for broad beans,

and 30 t/ha for forage crops, were obtained (Alvim and Veiguinha, 1962; Alvim, 1963).

Irrigated rice has been the main crop tried in the Sado's experimental field. Its adaptation to the "sapais", even under poor drainage conditions, has been succesful, with productions as high as 7,000 kg/ha, provided one applies enough flooding water at frequent intervals. In these drainage conditions, desalinization is very slow as it is carried on mainly by salt diffusion in the flooding water.

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SUMMARY

In Continental Portugal there are about 22,700 hectares of marine saline soils, named "sapais". Generally found in estuaries or lagoons, close to the sea, they show a dominance of clay and silt, and sometimes relatively high contents of sulphur compounds. As these soils have an important economical value, their reclamation and use is being studied both in the laboratory and in the field.

From the trials made, the following main conclusions were drawn:

1) possibility of reclaiming these Portuguese soils without irrigation;

2) efficiency of the lime treatment in cat clay reclamation;

3) reasonable response to the treatments used, of crops such as, under irrigation, rice and, without irrigation, wheat, barley, oats, broad beans, *Melilotus segetalis*, *Vicia atropurpurea* and *Lathyrus ochrus*.

RÉSUMÉ

Dans le Portugal Continental il y a environ 22 700 ha de sols salins marins, nommés „sapais". On les trouve généralement dans les estuaires ou les lagunes, près de la mer, ils montrent une prédominance d'argile et de limon très fin, et quelquefois des teneurs élevees en composés de soufre.

Comme ces sols ont une importante valeur économique, leur récupération et leur emploi sont étudiés, tant dans le laboratoire qu'au champ.

Des essais faits, les suivantes conclusions principales peuvent être tirées:

1) possibilité de récupérer ces sols portugais sans irrigation;

2) efficacité du chaulage pour l'amélioration de „cat clay";

3) réponse raisonnable aux traitements employés, pour des cultures telles que, sous irrigation, riz et sans irrigation, blé, orge, avoine, fève des marais, *Melilotus segetalis*, *Vicia atropurpurea* et *Lathyrus ochrus*.

ZUSAMMENFASSUNG

Im Festland-Portugal gibt es etwa 22 700 ha Meerufer-Salzböden, „Sapais" benannt. Gewöhnlich finden sie sich in Flussmündungen oder Lagunen vor, dicht an der See. Se weisen ein Überwiegen von Ton und Schluff und bisweilen verhältnismässig hohe Gehalte an Schwefelverbindungen auf.

Da diese Böden einen beträchtlichen wirtschaftlichen Wert darstellen, wurde ihre Nutzbarmachung und Nutzung sowohl im Laboratorium als auch im Feld untersucht.

Aus den durchgeführten Versuchen wurden folgende Hauptschlussfolgerungen gezogen:

1) Möglichkeit diese portugiesische Böden ohne Bewässerung nutzbar zu machen;

2) Wirksamkeit der Kalkung in der Pulvererde („cat clay")-Melioration;

3) angemessene Reaktion auf die angewendeten Behandlungen der Anbaupflanzen wie, unter Bewässerung, Reis, und ohne Bewässerung, Weizen, Gerste, Hafer, Pferdebohne, *Melilotus segetalis*, *Vicia atropurpurea* und *Lathyrus ochrus*.

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LES SOLS SALÉS ET ALCALISÉS EN PROFONDEUR DE LA PLAINE DU ZEBRA (BASSE MOULOUYA ; MAROC) : PREMIERS RÉSULTATS D'UNE EXPÉRIMENTATION DESTINÉE À ÉTUDIER LEUR AMÉLIORATION ET LEUR ÉVOLUTION SOUS IRRIGATION

ALAIN RUELLAN [1]

Située dans le Maroc Oriental, à 35 km de la Méditerranée, le long de la Moulouya, la plaine du Zebra, au climat sub-aride[2] doit être irriguée sur 10 000 hectares.

Cependant, l'étude pédologique entreprise en 1959, nous a rapidement montré que les sols de cette plaine sont très médiocres. Il s'agit, généralement, de sols bruns steppiques subtropicaux (classification francaise: Aubert, 1962), calcaires dès la surface (15—25%), que l'on peut classer, sur le plan agronomique, en deux groupes :

— les sols profonds: l'accumulation de calcaire, commençant vers 30—50 cm se fait sous la forme de taches ou granules et dose 25 à 45% ;

— les sols peu profonds (30—50 cm) : l'accumulation de calcaire, qui limite la profondeur, est une croûte calcaire, souvent coiffée par une dalle (2 à 20 cm). Les croûtes peuvent avoir 30 à plus de 100 cm d'épaisseur et contenir 55 à 90% de calcaire.

La texture de ces sols est souvent très fine en profondeur. Dans les sols profonds, la teneur en argile augmente progressivement avec la profondeur, atteint un maximum de 35—55% vers 50—80 cm, puis rediminue un peu. Dans les sols peu profonds et sous les croûtes, la texture est généralement moins fine.

Mais ce qui caractérise surtout ces sols, sur le plan de la mise en valeur, c'est d'une part la salure et l'alcalisation qui les affectent en profondeur (pédogenèses anciennes ou origine pétrographique : il n'y a pas de nappe phréatique), d'autre part l'instabilité structurale. Dans les sols profonds, la conductivité de l'extrait de saturation oscille généralement entre 8 et 20 mmhos à partir de 40—50 cm de profondeur (ClNa domine), et l'alcalisation, jugée d'après les pH, peut commencer à 30 cm ; les pH eau[3] oscillent

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[1] Office National des Irrigations, Berkane, MAROC. Pédologue O.R.S.T.O.M.

[2] Pluviométrie moyenne annuelle : 250—300 mm ; température moyenne annuelle : 19°C ; température maxima moyenne : 35°C. en Juillet Août ; température minima moyenne : 3°C. en Janvier-Février ; indice de THORNTWAITE : — 39,5 D B'3 da'.

[3] Pour la mesure du pH : terre/eau ou KCl normal : 1/2,5.

entre 8,5 et 9,3 et les pH KCl entre 7,7 et 8,2. Dans les sols peu profonds, la salure, qui commence dans la croûte, peut être encore plus forte (jusqu'à 30 mmhos), et l'alcalisation qui commence un peu au-dessus de la croûte, peut être très violente dans celle-ci : les pH eau peuvent atteindre 9,5—9,8 et les pH KCl 8,3—8,5.

Quant à l'instabilité structurale, nous l'avons mesurée par la méthode Henin (1960) : les Is oscillent généralement entre 2 et 5 en surface, 5 et 20 en profondeur (quelquefois plus) ; et la perméabilité mesurée au laboratoire est généralement de 5 à 10 cm/h en surface, 1 à 4 en profondeur.

La mise en valeur de ces sols pose donc des problèmes assez complexes. Sans parler de ceux qui sont liés à la présence du calcaire, l'existence de ces salure et alcalisation, de l'instabilité structurale en profondeur dans des horizons argileux mais aussi en surface, impose des améliorations préalables, une mise en eau prudente du périmètre irrigué, un choix judicieux des cultures et des méthodes de travail du sol.

Dès 1960, nous avons entrepris d'essayer de résoudre ces problèmes :

— par des essais au laboratoire ;

— et surtout par une expérimentation sur le terrain : sur une petite surface d'abord (200 m²) puis en station expérimentale (trois hectares ; 144 parcelles ; essais sur deux types de sols : un sol profond et un sol peu profond sur croûte calcaire tendre de 50 cm d'épaisseur).

Dans cette note nous donnerons l'essentiel des résultats déjà obtenus en particulier en micro-expérimentation (type de sol profond : voir tableau no. 1). Cependant, nous insisterons d'abord sur certains problèmes de méthodes d'analyses que nous avons eu à aborder : l'étude de l'évolution du complexe adsorbant d'un sol calcaire et salé n'est pas facile ; nous indiquerons rapidement les principales difficultés que nous avons rencontrées et comment nous les avons provisoirement résolues.

Tableau 1

Principaux résultats d'analyse du sol avant irrigation (moyenne de 11 profils de 6 à 9 échantillons chacun) (parcelles micro-expérimentation)

Profond. cm	Granulométrie (% de terre fine)					Terre fine %
	Argile 0—2 μ	Limons 2—20 μ	Argile + limons	Sables fins 20—200 μ	Sables grossiers 0,2—2 mm	
2	24,4	20,6	45,0	46,5	8,5	96,1
8	26,0	28,0	54,0	38,1	7,9	96,9
11	30,0	28,9	58,9	35,0	6,1	96,9
19	32,9	32,2	65,1	29,8	5,1	96,7
26	36,7	29,4	66,1	29,0	4,9	96,4
36	38,7	31,1	69,8	26,8	3,4	97,4
45	42,2	28,3	70,5	26,6	2,9	97,6
56	46,9	31,0	77,9	20,6	1,5	98,7
69	50,7	31,0	81,7	17,5	0,8	99,3
82	48,4	27,7	76,1	21,8	2,1	98,8
96	47,4	28,2	75,6	23,6	0,8	98,8

Profond. cm	CO_3 Ca total %	Mat. org. %	Salure		pH		Is et K		
			Extr. Aqueux gr/kg	Extr. saturé cond. mmhos	Eau	KCl	Profond. cm	Is	K cm/h
2	19,8	1,68	0,95	1,20	8,80	7,80	0— 10	3,0	5,5
8	19,3	1,32	0,88	0,94	8,70	7,80			
11	19,8	1,30	0,90	1,10	8,75	7,75	10— 20	2,5	10,0
19	20,6	0,84	0,93	1,26	8,75	7,70			
26	20,9	0,86	1,07	1,51	8,95	7,80			
36	22,3	0,66	2,11	4,66	8,95	7,90	25—35	3,5	8,0
45	23,9	0,49	3,88	8,66	8,70	7,90	40—50	4,5	5,0
56	24,3	0,29	5,22	10,66	8,65	8,00			
69	24,6	0,23	5,58	12,01	8,50	7,90	55—70	6,0	2,5
82	26,1	0,16	5,77	12,48	8,55	7,90	75—90	10,0	2,2
96	26,4	0,13	5,78	12,29	8,55	7,90	100—120	14,0	2,5

I. ANALYSE DE L'ALCALISATION

Les résultats résumés ci-dessous proviennent de l'étude de près de 900 échantillons sur lesquels les analyses suivantes furent réalisées :

— pH : eau, KCl, pâte saturée ;

— extrait 1/5 à l'eau distillée (E.A.) : mesure de la conductivité, des anions (Cl, SO_4, CO_3, CO_3H) et des cations (Na, K, Ca, Mg) ;

— extrait de saturation (E.S.) ; idem E.A ;

— extrait par NH_4 Ac normal, pH 8,5 (E.Ac) : dosages des cations ;

— extrait par NH_4Cl normal, pH 8,5 (E.Cl) : dosages des cations, puis extrait par KNO_3 normal pour déterminer la capacité d'échange T.

Le but essentiel que nous essayons d'atteindre est celui de la mesure de l'alcalisation : cette alcalisation est-elle seulement sodique et peut-on l'estimer correctement par la simple et rapide mesure du pH? Ce dernier point est important étant donné que sur la station expérimentale chaque série de prélèvements d'échantillons pour controler l'évolution des sols en contient 864. Nous avons donc d'abord comparé les différents extraits entre eux, puis nous avons essayé de relier au pH la composition de ces extraits. De nombreuses corrélations ont été étudiées : nous nous contenterons de citer ci-dessous les résultats importants.

A. COMPARAISON DES EXTRAITS

Pour le sodium, on constate le plus souvent que :

— l'E.Ac n'extrait pas tout le sodium (soluble + échangeable). Ce résultat est étonnant, mais nous l'avons maintes fois vérifié ; très souvent l'E.A. extrait plus de sodium que l'E.Ac et cela arrive même quelquefois pour l'E.S. ;

— l'E.A. extrait toujours plus de sodium que l'E.S., et souvent, par contre il contient moins de chlore; ce dernier point rejoint les résultats de Bower et Hatcher (1962). Il semble donc que l'E.S. surestime un peu le sodium soluble, et surtout que l'E.A. extrait une partie du sodium échangeable ;

— c'est l'E.Cl qui extrait le mieux le sodium soluble plus échangeable, et il semble que le sodium échangeable puisse être pris comme égal à Na E.Cl

— Na E.S. (Na E.S. préalablement corrigé en multipliant par Cl E.A./Cl E.S.) ;

— cependant, nous n'avons pas encore réussi à mesurer T d'une façon précise, ni par $ClNH_4$ — NO_3K, ni par aucune autre méthode classique (Cl_2 βa, A.C. NH_4) ; ceci provient certainement de la richesse en calcaire et peut-être aussi de la présence de sels peu solubles. Ie en résulte que nous ne connaissons pas Na/T avec précision.

Pour le calcium l'E.Ac en contient toujours plus que l'E.Cl : c'est un résultat connu. Mais il contient également souvent plus de magnésium : ceci indique qu'une partie du calcaire est du CO_3Mg dont nous verrons l'énorme influence sur les pH.

B. RELATIONS ENTRE pH ET COMPOSITION DES EXTRAITS

La mesure exacte des T ayant été impossible, nous avons cherché à relier le pH avec la composition des E.A. et E.S.

De multiples rapports ont été étudiés. Mais jusqu'à présent un seul donne des résultats intéressants : Na/Ca dans l'E.S. (fig. 1) :

— ce rapport est parfaitement lié au pH eau, en fonction bien entendu de la conductivité de l'E.S. L'étude statistique donne des corrélations très hautement significatives ;

— il est également très bien relié au pH KCl, et ici indépendamment de la conductivité ;

— nous n'avons pas encore étudié de près la corrélation avec le pH pâte saturée. Elle semble cependant moins bonne, ceci provenant probablement de l'imprécision du pH.

Parmi les rapports étudiés, nous n'avons pas oublié l'E.S.P. déduit du SAR de l'E.S. (U.S.S,L.S. ; 1954). Mais nous avons constaté que si la corrélation avec le pH eau est bonne pour des salures (fig. 2) très faibles, elle devient rapidement mauvaise quand la salure augmente : elle est nulle quand la conductivité dépasse 12 mmhos. La relation entre pH KCl et E.S.P.E.S. est meilleure, mais elle n'égale pas celle existant entre pH KCl et Na/Ca E.S. Nous pensons que ceci provient de l'influence du magnésium sur l'alcalisation ; l'E.Cl extrait toujours beaucoup de magnésium, quelquefois plus que de calcium ; nous n'avons cependant pas encore réussi à étudier une relation entre ce magnésium échangeable et les pH étant donnée l'absence de chiffres pour T.

Afin de déterminer à partir de quelle valeur de Na/Ca E.S. on peut parler d'alcalisation sodique, nous avons établi la relation existant entre

ce rapport et l'E.S.P. Cette relation est assez faible. On peut cependant estimer q'il y a alcalisation quand Na/Ca > 5, ce qui correspond à E.S.P. = 10 — 15 (ce chiffre a été confirmé sur quelques échantillons pour lesquels

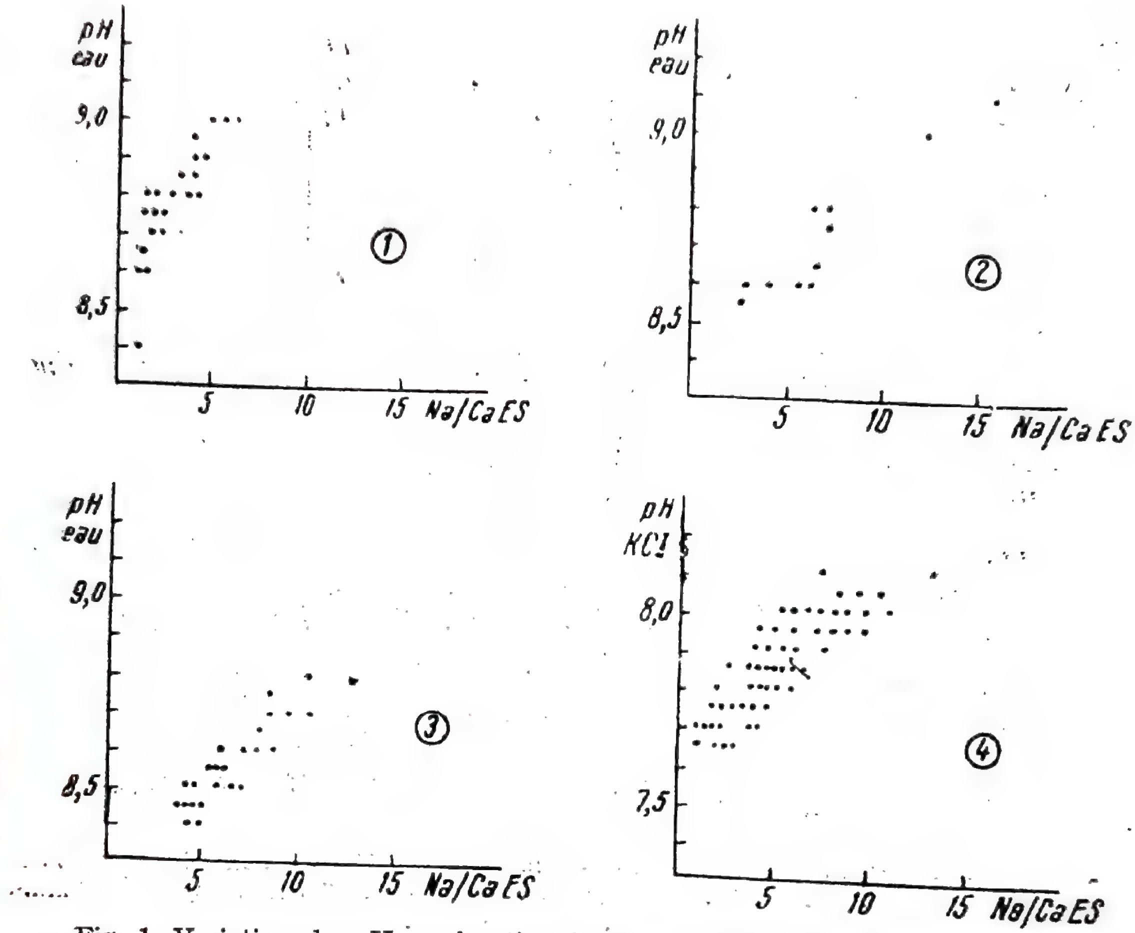

Fig. 1. Variation du pH en fonction du rapport Na/Ca dans l'extrait de saturation. La conductivité de cet extrait est de :— 0—4 mmhos en (1) — 4—9 mmhos en (2) — > 9 mmhos en (3).

nous avons obtenu des valeurs approximatives de T). Si nous nous reportons alors aux relations pH- Na/Ca, on constate que Na/Ca = 5 correspond à

— pH KCl = 7,8 — 7,9,

— pH eau = 9,0 quand la conductivité < 4 mmhos,

= 8,6 — 8,7 quand la conductivité < 9 mmhos,

= 8,4 — 8,5 quand la conductivité > 9 mmhos.

On remarquera tout de suite que ces chiffres de pH sont très élevés et ceci nous a amené à rechercher une autre raison à l'alcalisation. Nous n'avons pu encore établir l'action exacte du magnésium échangeable, mais après avoir déterminé la présence certaine d'environ 1 a 5% de CO_3Mg dans tous les sols, nous avons étudié, sur une terre non calcaire, l'action du CO_3Mg sur les pH, en absence et en présence de quantités variables de CO_3Ca.

Les résultats essentiels sont consignés sur la figure 3 : l'action du CO_3Mg est foudroyante ; en l'absence de CO_3Ca, il suffit de 1% de CO_3Mg pour amener le pH eau de 8,1 à 9,0 le pH KCl de 6,6 à 7,8 et le pH pâte saturée

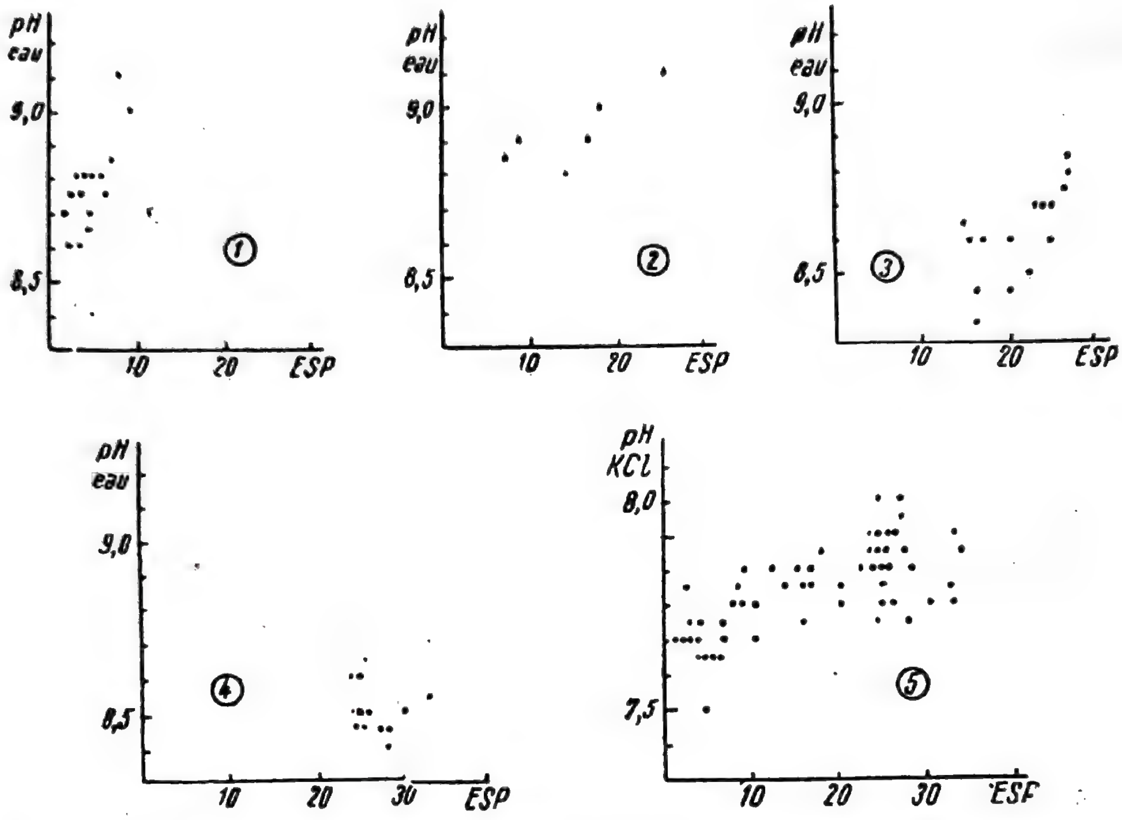

Fig. 2. Variation du pH en fonction de ESP calculé d'après SAR de l'extrait de saturation. La conductivité de cet extrait est de : — 0—2 mmhos en (1) — 2—6 mm en (2) —6—12 mmhos en (3) > 12 mmhos en (4).

de 7,75 à 8,9 ; pour 2,5% les pH sont respectivement de 9,3 à 8,3 et 9,1. La présence de CO_3Ca augmente encore le pH. Il serait donc possible qu'une grande partie de l'alcalisation des sols du Zebra soit due à la présence de CO_3Mg.

II. ÉVOLUTION DES SOLS

Quelques mots d'abord sur l'eau d'irrigation utilisée (voir tableau 2). Elle est légèrement salée : sous le climat très évaporant du Zebra, son action sur la salinisation des sols ne doit pas être sous estimée. Mais la composition de cette salure est favorable : en milliéquivalents, elle contient 30 à 60% de SO_4Ca ; une irrigation annuelle de 10 000 m³/ha apporte 3 à 7 tonnes de plâtre. Cependant, elle contient également beaucoup de magnésium.

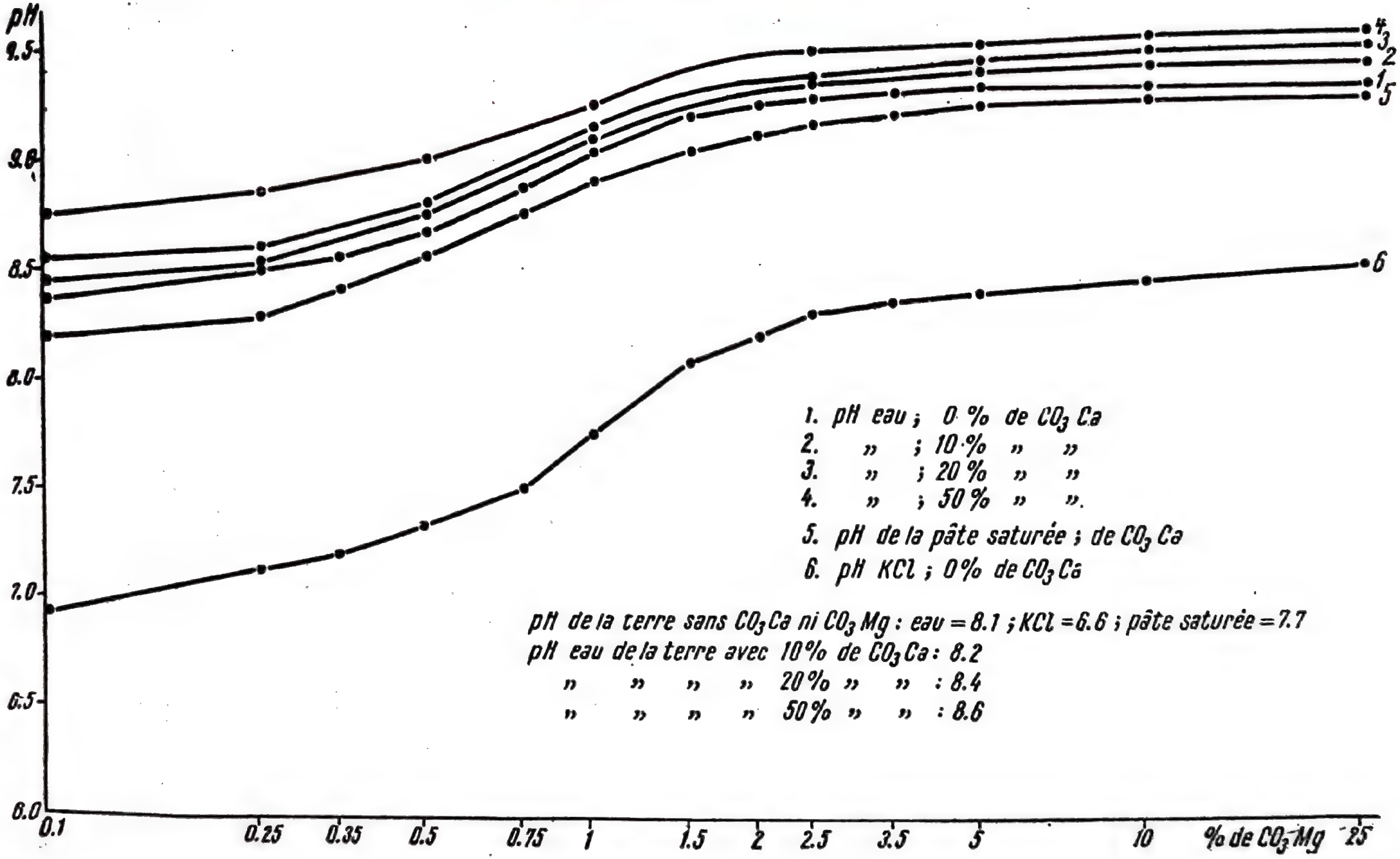

Fig. 3. Action du CO_3Mg et du CO_3Ca sur le pH d'une terre non calcaire.

VI. 32

Tableau 2

Quelques résultats d'analyses de l'eau de la Moulouya

Période :	Date	Ca meq/l	Mg me/l	Na me/l	K me/l	SO_4 me/l	Cl me/l	CO_3 me/l	CO_3H me/l	Anions + cations mg/l	Cond. mmhos	SAR
Automne : 1° crues maxima de salure	28.10.60	5,8	5,0	5,65	0,10	7,5	7,0	0,0	2,9	1917	1,62	2,4
	27.10.61	6,2	4,6	6,0	0,15	9,0	5,5	0,0	2,8	1121	1,48	2,6
Hiver : minima de salure	8.2.60	3,3	2,3	1,8	0,05	2,5	2,0	0,0	3,1	522	0,78	1,0
	3.2.61	2,9	1,8	1,4	0,05	1,75	1,25	0,0	3,1	432	0,63	0,9
Printemps : salure moyenne	14.4.61	3,7	2,3	2,35	0,10	3,75	2,1	0,0	2,5	555	0,83	1,3
	8.6.62	3,5	3,0	2,35	0,10	4,2	3,0	0,2	2,1	606	0,85	1,3
Été : étiage salure moyenne	21.7.61	4,6	3,0	3,0	0,10	5,0	3,25	0,0	2,3	699	1,11	1,6
	20.7.62	3,85	4,9	4,0	0,10	4,2	3,5	0,4	2,6	732	1,20	1,0

Après quatre années d'expérimentation, nos résultats actuels sont, sous une forme résumée, les suivants :

A. *Salure*

Le dessalage des sols profonds, jusqu'à plus d'un mètre de profondeur, est facile : il est immédiat si on réalise une submersion (5 000 m^3/ha) ; il demande environ un an si à chaque irrigation on augmente les doses d'environ 40%. La salure est ramenée à $1^0/_{00}$ (extrait de saturation : 1 à 2 mmhos). Le dessalage des croûtes et des horizons situés sous la croûte, est plus long.

Une fois le dessalage réalisé, il faut continuer à lutter contre l'accumulation des sels provenant de l'eau d'irrigation. Cette accumulation se produit surtout sous culture billonée, dans le billon, le travail du sol amenant ensuite ce sel plus profondément : en quelques mois d'irrigation, on obtient 3 à $12^0/_{00}$ de sels totaux sur le sommet du billon et en quelques années 1,5 à $5^0/_{00}$ dans les 30 premiers cm. du sol. Ces sels étant cependant surtout du SO_4Ca, il ne faut pas surestimer leurs dangers : la conductivité de l'extrait de saturation dépasse rarement 10 mmhos ; cela nous semble malgré tout suffisant pour conseiller la lutte contre cette accumulation, lutte qui ne peut se faire que sous la forme de lessivages annuels ; l'augmentation des doses à chaque irrigation entraîne trop de gaspillage et ne peut empêcher la salinisation des billons.

B. *Structure et perméabilité*

Sous culture de luzerne, recevant 20 000 m^3 d'eau par hectare et par an, l'évolution de l'horizon profond argileux est le suivant :

— la stabilité structurale reste très faible : Is de 4 à 10, mais semble s'améliorer légèrement ;

— la perméabilité mesurée au laboratoire s'est améliorée : elle est maintenant de 3 à 5 cm/h au delà de 50 cm de profondeur ;

— par contre la perméabilité mesurée sur le terrain (Muntz) avec de l'eau dosant 0,6 g/l, reste très faible : 0,2—0,3 cm/h.

Cependant, malgré des irrigations souvent massives, aucune difficulté de drainage n'est apparue : nous attribuons ceci à la légère salure de l'eau d'irrigation

Pour l'évolution des horizons de surface, il faut distinguer deux cas :

1. *Irrigation par calants* (luzerne) : il s'agit en somme d'une petite submersion. On observe une destruction importante de la structure sur les 10—30 premiers cm, se traduisant par une augmentation des Is, souvent très importante (variable suivant les types de sols). Par contre, sous cet horizon détruit, entre 10—30 et 50 cm, la luzerne fait du bon travail : les Is diminuent. En ce qui concerne la perméabilité, celle mesurée au laboratoire enregistre une baisse importante dans l'horizon détruit : elle peut tomber à 1 cm/h. Par contre, elle a tendance à s'améliorer un peu entre 10—30 et 50 cm. Enfin la perméabilité mesurée sur le terrain n'enregistre pas cette destruction de la structure : au contraire, elle peut passer de 1 à 3 cm/h, ceci étant probablement dû à la porosité en grand créée par l'enracinement de la luzerne.

L'irrigation par calant d'une luzerne gène donc considérablement l'amélioration de la structure qu'on en attend. On peut lutter contre ceci par un travail correct du sol (sacrifiages), mais il serait surtout nécessaire de changer de méthode d'irrigation (billon plat, aspersion).

2. *Irrigation à la raie* : le mauvais travail du sol (charrue à disque : 15 cm ; pas de scarifiage ; peu de binnages), entraîne rapidement la destruction de la structure sur les 30 premiers cm. et surtout l'apparition entre 15 et 30 cm d'un horizon noirci, trés compact, que les racines pénètrent très difficilement : c'est l'action de l'irrigation sur la semelle de labour. Perméabilité et stabilité structurale y sont très faibles : Is y oscille souvent entre 10 et 20. À signaler également que toute la vie animale se développe juste sous cet horizon. Il est bien entendu facile de lutter contre cette dégradation qui limite très sensiblement les rendements, en particulier par des scarifiages profonds (35—40 cm), par des apports de matière organique, et par l'amélioration du système d'irrigation : rétrécissement et approfondissement des raies.

C. *Alcalisation*

La perméabilité s'étant maintenue, la désalcalisation sodique, sur sol profond, s'est faite sans difficulté, jusqu'à 1 mètre de profondeur, en 18 mois, ceci sans aucun apport de gypse ; un essai d'apport en surface de 14 T/ha

de plâtre n'a nullement accéléré le phénomène. Nous avons pu suivre de près cette désalcalisation par l'extrait de saturation ; voir le rapport Cl/SO_4 passer rapidement (en 8 mois à 80 cm) de 10—15 à 1 ; voir ensuite succesivement chaque horizon recevoir le sodium désorbé au-dessus, puis lui-même perdre son sodium. En 18 mois, le rapport Na/Ca fut ramené de 6—8 à 0,5—1 et l'E.S.P. (SAR) de 20—30 à 2—5. Quant aux pH, ils ont d'abord enregistré une augmentation due au dessalage, puis ils ont diminué au fur et à mesure du départ du sodium ; cependant actuellement, après 4 ans d'irrigation, ils se sont stabilisés à 8,8—9,0.

Certains essais de laboratoire ayant démontré que :

1) l'eau de la Moulouya, en désorbant le sodium, le remplace en partie par du mangésium ;

2) des percolations à l'eau gypseuse (1 g/l) peuvent abaisser le pH eau jusqu'à 8,6—8,7, ceci correspondant à une désorption importante de magnésium et peut-être aussi de CO_3Mg ; nous irriguons depuis trois ans certaines parcelles de la station expérimentale avec de l'eau enrichie en gypse (0,6 gr/l dans le canal d'irrigation ; il n'en arrive que 0,2—0,3 à la parcelle). Il semble que ces apports de gypse commencent à marquer (en 1963 sur sol peu profond, une culture de coton a donné 19 quintaux/hectare avec gypse, 16 sans gypse, ceci correspondant à une diminution du pH de 0,2 unité). Nous allons essayer en 1964 d'accélérer le phénomène en augmentant les doses de gypse et par des apports d'SO_4H_2.

D. *Comportement des cultures*

Trois cultures ont été jusqu'à présent essayées régulièrement : coton, betterave, luzerne.

Il est très net que ces cultures souffrent des pH trop élevés, probablement à cause du blocage des éléments assimilables (oligo-éléments en particulier). La betterave en particulier donne de trés mauvais résultats : 15 à 20 T/ha de racines mal formées. La luzerne donne des résultats médiocres : 40 à 60 T/ha de foin humide. Seul le coton donne des résultats corrects : 15 à 20 qtx/ha. Aucune culture n'a enregistré par un meilleur rendement, le dessalage et la désalcalisation sodique.

IV. CONCLUSIONS

Après quatre années d'expérimentation, nous pouvons donc provisoirement conclure que :

1. Il n'y a pas de difficulté de draînage en profondeur. Mais il faut lutter en permanence contre la dégradation de la structure des horizons de surface.

2. Le dessalage en profondeur est facile, mais il faut lutter contre l'accumulation en surface des sels amenés par l'eau d'irrigation.

3. La désalcalisation sodique est facile ; mais elle n'est pas suffisante : les pH restent élevés et les rendements faibles ; ceci semble dû à une alcalisation magnésienne: magnésium adsorbé et CO_3Mg ; alcalisation magnésienne beaucoup plus difficile à éliminer.

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RÉSUMÉ

Trois années d'essais sur le terrain et au laboratoire pour tenter d'améliorer, en périmètre irrigué, des sols bruns steppiques qui sont très calcaires, et en profondeur, fortement salés alcalisés et argileux, ont donné les premiers résultats suivants :

— pour mesurer le Na échangeable, on peut se contenter de la différence entre le Na extrait par du $ClNH_4$ et celui contenu dans l'extrait de saturation;

— la mesure de la capacité d'échange est très délicate;

— le rapport Na/Ca, contenus dans l'extrait de saturation donne une meilleure vue de l'alcalisation que le E.S.P. calculé d'après le S. A. R. (Riverside);

— u ne partie de l'alcalinisation est due à la présence de faibles quantités de CO_3Mg;

— le dessalage et la désalcalisation des sols se fait repidement par la simple utilisation de l'eau d'irrigation qui est riche en SO_4Ca. Cependant, les pH restent élevés (voisins de 9,0). Les aports en gypse ont peu d'effet. L'évolution de la structure du sol et le comportement des cultures ont été également étudiés.

SUMMARY

Three years of investigations under field and laboratory conditions to attempt the melioration, in an irrigated perimeter, of brown calcareous steppe soils, which in depth are very saline, alcalized and clayey, have given the following results :

— for the purpose of measuring the exchangeable Na, one may consider as sufficient the difference between the Na extracted by $ClNH_4$ and that contained in the saturation extract ;

— the measuring of the exchange capacity is very difficult;

— the Na/Ca ratio of the saturation extract gives a better view of the alkalisation than the E.S.P. calculated after S.A.R. (Riverside) ;

— part of the alkalisation is due to the presence of small CO_3Mg quantites;

— the desalinisation and the reduction of alcalisation of the soils occur rapidly by the simple utilization of irrigation water rich in SO_4Ca. Nevertheless, the pH remains high (next to 9.0). The gypsum contribution is of little effect. The soil structure evolution and the crop behaviour were also studied.

ZUSAMMENFASSUNG

Die durch drei Jahre durchgeführten Feld- und Laboratoriumversuche zwecks Erzielung der Melioration, auf einer bewässerten Fläche, von braunen, sehr kalkhaltigen und in der Tiefe sehr versalzten, alkalisierten und tonhaltigen Steppenböden, haben folgende erste Ergebnisse gezeitigt:

— um das austauschbare Na zu messen, kann man sich mit der Differenz zwischen dem durch $ClNH_4$ ausgeschiedenen Na und mit dem in Sättigungsextrakt enthaltenen, begnügen;

— die Messung der Austauschkapazität ist sehr delikat;

— das Verhältnis der im Sättigungsextrakt enthaltenen Na/Ca vermittelt eine bessere Einsicht über die Alkalisierung als der E.S.P., nach dem S.A.R. (Riverside) berechnet;

— ein Teil der Alkalisierung ist dem Vorhandensein von geringen CO_3Mg-Mengen zuzuschreiben;

— die Entsalzung und die Entalkalisierung der Böden geht rasch durch die einfache Benützung des an SO_4Ca reichen Bewässerungswassers vor sich. Dabei bleiben die pH hoch (nahe von 9,0). Die Gipsgaben sind von nur geringer Wirkung. Es wurden desgleichen die Entwicklung der Bodenstruktur und das Verhalten der Kulturen studiert.

DISCUSSION

H. P. MIRIMANIAN (U.S.S.R.). I would like to know whats is the oil-forming parent material in the lower horizons of soils—are there any sedimentary deposits or the products of the weathering of the igneous rocks or volcanic ash.

A. RUELLAN. Il s'agit d'alluvions et de colluvions déposées dans les plaines au cours des périodes pluviales succesives du quaternaire.

P. JANITZKY (U.S.A.). What attempts have been made to determine exchangeable Ca and Mg in the presence of such high amounts of $CaCO_3$ and $MgCO_3$?

What are the results of additions of sulfuric acid in order to activate $MgCO_3$?

In California there are soils with high unfavourable physical properties. It seems to me that the activation of $MgCO_3$ might bring about a decrease in the permeability of the irrigated plots.

A. RUELLAN. 1. J'ai essayé plusieurs méthodes. L'extraction par l'acidase d'ammonium ou acétate de sodium n'est pas valable car la dissolution du Ca_3CO_3 et CO_3Mg est très forte. Par contre l'extraction par le chlorure d'ammonium normal en solution alcoolique, tamponné à pH 8,5 donne de bons résultats. J'ai pu établir une très bonne corrélation entre le rapport Na/Ca de l'extrait au $ClNH_4$ (après soustraction de ce que contient l'extrait de saturation), et le rapport Na/Ca de l'extrait de saturation. Cependant j'estime qu'il n'existe aucune méthode valable pour déterminer la capacité d'échange.

2. Il y a peu de CO_3Mg par rapport au CO_3Ca; je pense donc qu'il ne peut y avoir de problèmes bien que le CO_3Mg se détruise plus vite que le CO_3Ca sous l'action de l'acide sulfurique dilué (N/100).

8th INTERN. CONGRESS OF SOIL SCIENCE, BUCHAREST, ROMANIA, 1964

CHANGES IN FABRIC AND PROPERTIES OF DESERT (TAKYR) SOILS UNDER LONG IRRIGATION

N. G. MINASHINA [1]

Murgab oasis, known under name Margiana in antique times and later as Mervski, is situated in the vast dry delta of the Murgab river and surrounded by the sand desert of South-Eastern Karakums. A regular irrigation of middle terraces and dry part of the delta has been carried on from ancient times. A considerable part of the oasis was devastated during the Mongolian invasion. Now Takyr and Takyr-like soils are widely distributed on the devastated part of the ancient oasis. The most mature Takyrs occur in the old marginal part of the delta between desert sand hills. Part of the desert lands has been irrigated again after the construction of Karakum Canal.

Desert takyr soils have shallow profiles. The topsoil crust, 4—7 cm. thick, is cracked and porous, beneath there a foliaceous-lamellar horizon to the depth 15—18 cm which passes into a more compact coarsely granular-platy layer. Parent material presented by alluvial fig. 1.or old irrigational deposits fig. 2. occurs at the depth 50—60 cm, humus content is 0.2—0.5%, $Ca\ CO_3$ content is rather high- 15–20% table 1. The soils are very often saline. Maximum of the water soluble salts are found at the depth of 20—60 cm from the top of the soil. The desert soils are sometimes also, alkaline. Exchangeable cations are predominantly presented by calcium (70—80% of C.E.C.). There are small quantities of magnesium, potassium (about 5%) and seldom sodium in soils on old irrigation deposits. The takyr soil formed in the northern margin of the delta contains high percentage of exchangeable sodium up to 15% of C.E.C. of the soils is not more than 10 me/100 g. Independently of the composition of the exchangeable cations the desert soils are characterized by the absence of the water-stable silt aggregates and microaggregates. Soil clay minerals are readily dispersed on moistening; after rain the soil surface becomes sticky and very little permeable but after drying hard and cracked.

The micromorphological investigation of the soil in thin section shows that optically oriented clay particles form dense clothes indicating a fine texture of the clay fig. 3. The greatest quantity of the optical oriented clays are found in the upper part of the soil profile where they get peptized on moistening.

The clay minerals of desert soils form stable colloidal solutions which readily move upward in experimental sand columns. This calcium and coarse gypsum layers in the columns of sand do not impede the colloids to rise. On

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Physical and chemical properties of the Murgab soils

Depth cm	% on dry soil			Exchangeable bases											
	Humus	N	P_2O_5	K_2O	Ca^{++}	Mg^{++}	Na^+	K^+	CEC mequ	$CaCO_3$ %	$CaSO_4$ $2H_2O$ %	Soluble salts %	Clay < 0,001 mm	Volume weight	Porosity %
					% ou C.E.C										
					Takyr desert soil										
0— 6	0.46	0.06	0.13	1.45	7.20	8.5	12.4	7.1	9.4	13.4	0	0.10	15.3	1.61	41
10— 16	0.28	0.02	N.D.		75.3	3.7	14.8	6.2	10.6	13.6	0	0.20	14.8	1.60	42
24— 34	0.36	0.04	0.13	1.38	Not determined					16.8	3.4	2.00	18.2	1.62	40
60— 66	0.30		ND		"		"			19.1	1.2	2.20	23.0	1.75	35
155—161	0.28		ND		"		"			20.7	0.2	0.90	3.1	1.78	35
180—185	0.22		ND		"		"			14.5	0.6	0.60	11.8	1.82	33
					Old irrigated soil										
0— 10	1.10	0.07	0.17	1.35	60.9	31.4	2.1	5.6	10.9	18.4	0.10	0.06	15.5	1.30	52
15— 25	1.10	0.05	N.D.		55.9	36.5	2.1	5.5	12.3	18.4	0.12	0.06	14.5	1.46	46
35— 45	0.98	0.03	0.17	1.54	64.8	28.3	2.4	4.5	13 1	18.1	0.08	0.06	21.5	1.56	43
62— 72	0.64	Not determined			57.5	36.3	2.1	4.1	8.7	16.3	0.02	0.05	13.6	1.50	45
81— 91	0.55	"	"		53.9	41.4	2.2	2.5	12.8	17.9	0.04	0.06	11.4	1.39	48
106—116	0.58	"	"		46.0	49.9	1.8	2.3	13.3	20.4	0.07	0.05	16.3	1.59	44
170—180	0.35		0.13	1.29	49.2	44.9	3.0	2.9	5.9	16.3	0.05	0.01	3.8	1.34	51

Fig. 1. Structure of the alluvial clay-silt deposits. $10 \times 3{,}5$.

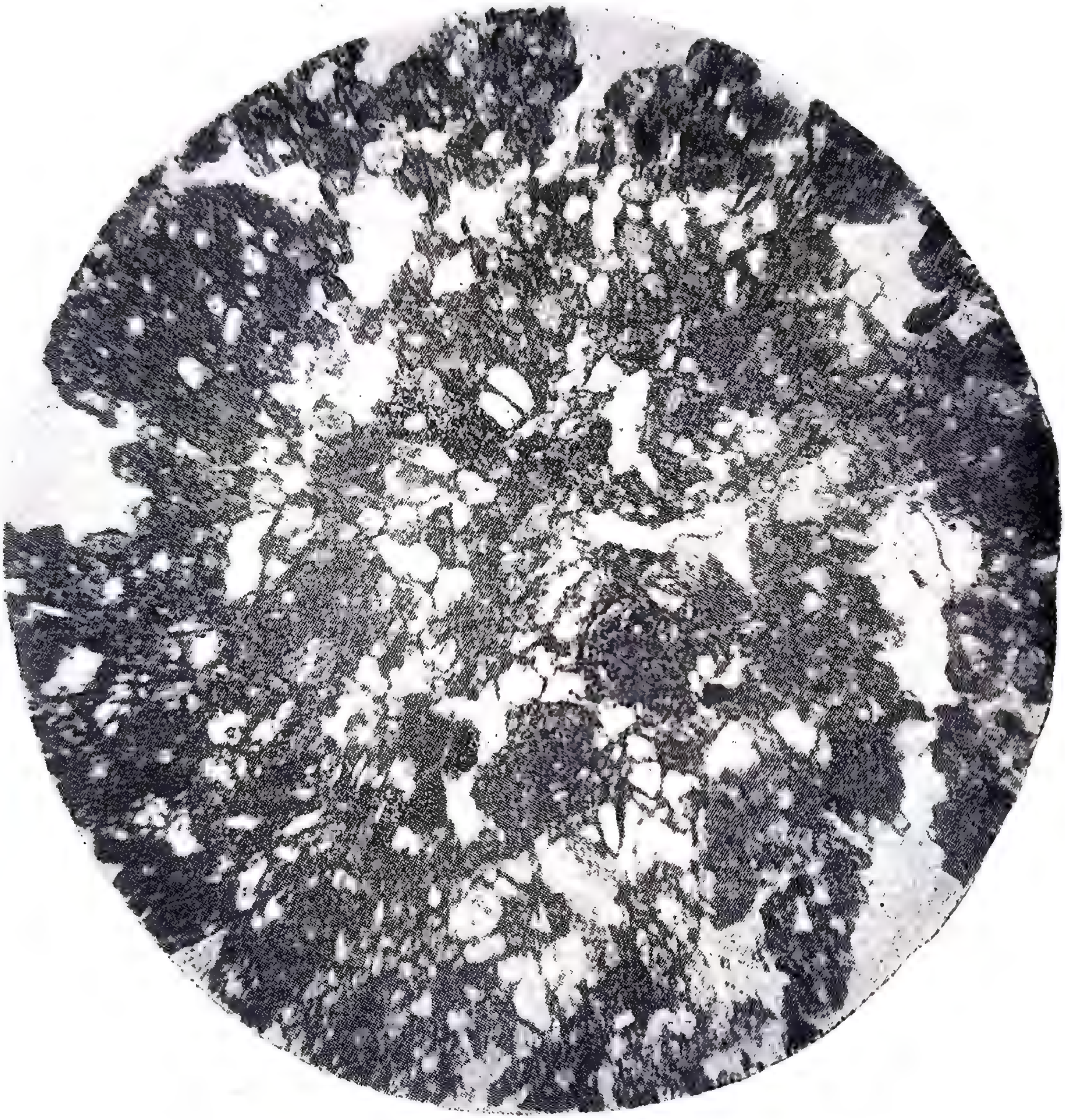

Fig. 2. Microstructure of old agroirrigational deposits. 10×3,5.

Fig. 3. Structure of the desert takyr crust. 10×9.

drying the colloid solutions, clay minerals form dense films of oriented particles on the sand grains.

Under natural conditions, clay particles from the soil also become very mobile in the moist state of the soil, they move and accumulate in depressions after rain, forming on drying a smooth pink surface. In places of superficial water accumulation, takyrs are formed and as pink algae. High dispersion and mobility of the soil clay minerals are the main reasons for their unfavourable water relationships for crops.

The clay fraction (<0.001 mm) of the upper horizon of desert soils is characterized by a high content of MgO (6—8%) calculated on the noncalcarous ignition sample. Colloidal fraction (<0.00025 mm) extracted from the takyr crust, contains still more magnesium sillicates (MgO—12% R_2O_3 — 27%, SiO_2 — 48%) on ignition sample. The clay minerals found in the clay fraction (less than 0,001 mm) are as follows: hydromicas, montmorillonite, kaolinite and magnesium silicate, probably belonging to the palygorskite group. During desert soil formation, magnesium is fixed by the clay fraction of the soils.

OLD IRRIGATED SOILS

At the first stage of irrigation the desert soils (takyr and takyr-like) are leached by water. They lose soluble salts and some humus. Their physical properties become worse than before because of deterioration of structure and dispersion of clay particles, filling up the hollow canals and chambers in the soils. This stage is the most difficult reclamation period. Cotton yields on this soils are very low. Under long irrigation, physical properties of the desert soils are gradually being improved due to plant residues and humus accumulation up to 1—2% and the appearance of the new microorganisms and fauna and their activation. The soils of the oases formed in depresssions under poor local drainage conditions are not meant here. The large amount of carbon dioxide produced in irrigated soils, favours the dissolution of calcite. Besides, the Murgab-river water as source for irrigation, brings annually about 2 tons of water soluble calcium per hectars. All this lead to coagulation of soil colloid particles and changes soil microstructure and fabric. Soil clays are microaggregated and lose the mobility and optical orientation of their particles. The conditions of irrigated soils are favourable for earthworms which are absent in not irrigated desert soils. The number of earthworms in old cultivated soils reaches 2,000—2,500 per hectare, their total weight being about 1.5 ton/hectare. Earthworns pass annually through their alimentary tracts about 150 tons of soil mass per hectare (Brodski, 1937).

Under long irrigation, a thick layer of artificial deposits (2—3 m) have been formed on the surface of the pre-irrigated soils. The thickness of humus profile and organic carbon contents increased considerably under the influence of cultivation. The C:N ration of irrigated soils is wider than that of non-irrigated soils. Exchangeable sodium is almost absent in the old irrigated

soils. The amount of exchangeable magnesium is markedly higher than in natural desert soils. But calcium is predominant in the upper part of the cultivated soils. The changes in composition and fabric of the old irrigated soils are accompanied by the improving of their porosity and water permeability. The porosity changes from 40 to 52%, field water permeability changes from 0.01—0.1 millimeter per minute in desert takyr soils to 0,2—0,6 millimeter per minute in irrigated soils. In the irrigated soils, nutrient elements, particularly phosphorus, are accumulated due to appliance of a large amount of manure and fertilizers. In the thin section from old irrigated soils, one can see uniformly distributed humus-clay substance among sand-silt particles. Chemical composition of clay fraction of the soils contains more humus than desert soils and has a higher cation exchange capacity.

Condensed optically oriented clays are almost absent in well cultivated soils. The ground mass of the soils has microgranular structure and includes a lot of microcanals and chambers. There are many traces of activity of earthworms and insects. Subsoil layer of old cultivated soils is often very compact under cotton plant. In the deeper layers of the soils (40—100 cm and more) microaggregation is more clearly seen than in the arable layer; old agroirrigation deposits, subjacent contemporary soils, bear more evidence of active soil fauna, especially earthworms. Evidently, earlier, irrigated soils were very rich in organic matter, because of more humid conditions.

Soils of different oases are characterized by variable fabric of artificial horizons because of different composition of irrigated deposits, particularly their clay fraction. For example, old irrigated soils of Zeravshan valey are less microaggregated than in Murgab delta. The clay fraction of Zeravshan deposits consists of coarse hidromica particles which are slightly aggregated.

It is known that soils of different oases have different fertility. But old irrigated soils have everywhere many similar features, among those are: thick humus profiles, high humus content, uniform slightly differentiated soil profile, high nutrient content, well pronounced microaggregation, high calcium compound content, a favourable exchangeable cation and soluble salt composition. They contain the same clay minerals as takyr desert soils but less magnesium silicates (MgO in the clay fraction of the old irrigated soils is 3—5% on ignition bases).

CONCLUSION

The Murgab oasis known as Margiana in antique times and later as Mervski is situated in the vast dry delta of the Murgab river and surrounded by the sand desert of South-Eastern Karakums. A regular irrigation of the middle terraces and dry part of the delta has been carried out since ancient times. A considerable part of the oasis was devastated during the Mongolian invasion. At present, takyr and takyrlike soils are widely distributed on the devastated part of the ancient oasis.

The humus content is 0.2—0.5%, $CaCO_3$ — 15—20% without any obvious differentiation throughout the profile. The soils are very often saline. The maximum water-soluble salts are found at the depth of 20—30 cm. The desert soils are alkaline. Exchangeable cations are predominantly represented by calcium (70—80% of C.E.C.), small quantities of magnesium, potassium (about 5.7%) and seldom by sodium.

The micromorphological investigation of the soil in thin sections shows that optically oriented clay particles from dense coatings display the fine texture of the clay. The greatest quantity of the optically oriented clays is found in the upper part of the soil profile where they are peptized on moistening. The clay minerals of desert soils form stable colloidal solutions which readily move.

The clay minerals found in the clay fraction (less than 0.001 mm) are as follows: hydromicas, montmorillonite, kaolinite and magnesium silicate, probably belonging to the palygorskite group. During desert soil formation, magnesium is fixed in the soil clay fraction. Old irrigated soils of the same delta have different characteristics.

Under a long irrigation, soil clays are microaggregated and loose the mobility and optical orientation of their particles. The humus content increases in the soil up to 1—2.5%, the porosity changes from 38—45 to 45—52%, the field water permeability is being improved (in desert soils 0.01—0.1 mm/min, in cultivated old irrigated soils — 0.2—0.6 mm/min). They contain the same clay minerals as takyr desert soils, but less magnesium silicates (MgO in the clay fraction of the old irrigated soils is 3—5% on ignition bases).

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SUMMARY

Under a long irrigation, soil clays are microaggregated and lose the mobility and optical orientation of their particles. The humus content increases in the soil up to 1—2,5%, the porosity changes from 38—45 to 45—52%, the field water permeability is being improved (in desert soils 0.01—0.1 mm/min, in cultivated old irrigated soils 0.2—0.6 mm/min.). They contain the same clay minerals as takyr desert soils, but less magnesium silicates (MgO in the clay fraction of the old irrigated soils is 3—5% on ignition bases).

RÉSUMÉ

Sous une irrigation prolongée, les argiles du sol se sont formées en micro-agrégats et perdent la mobilité et l'orientation optique de leurs particules. La teneur en humus dans le sol augmente jusqu'à 1—2,5%, la porosité monte de 38—45 à 45—52%, la perméabilité de l'eau au champ a été améliorée (en sols désertiques 0,01—0,1 mm/min, en sols cultivés anciennement, irrigués 0,2—0,6 mm/min). Ils contiennent les mêmes minéraux argileux que les désertiques takyr, mais moins de silicates de magnésium (MgO dans la fraction d'argile des sols anciennement irrigués est de 3—5% rapporté au sol calciné).

ZUSAMMENFASSUNG

Während einer langandauernden Bewässerung zerfallen die Bodentone in Mikroagregate und verlieren die Mobilität und optische Orientierung ihrer Partikeln. Der Humusgehalt steigt im Boden bis zu 1—2,5%, die Porosität verdändert sich von 38—45 auf 45—52%, die Durchlässigkeit des Feldwassers verbessert sich im Wüstenboden mindestens um 0,01—0,1mm, in bebauten altbewässerten Böden mindestens um 0,2—0,6 mm. Sie enthalten dieselben Tonmineralien wie die Takyrwüstenböden, jedoch weniger Magnesium-Silikate (der MgO-Gehalt in den altbewässerten Böden ist 3—5% auf Kalzinierungsbasis).

DISCUSSION

G. AUBERT (France). Peut-on nous donner des précisions sur les caractéristiques chimiques de l'eau utilisée pour l'irrigation dans cet oasis?

N. G. MINASHINA. The chemical composition of the Murgaba waters: compact residuum for several years = 0,5 g/l, the calcium salt content being 30% in summer and approx. 50% in winter, sodic salts approx. 40—50% and the remainder being magnesium salts.

W. H. VAN DER MOLEN (Netherlands). The improvement of well-drained soils by applying water of good quality was obviously described by both M. Ruelan and Mrs. Minashina. The former observed the initial improvement. The latter the excellent soil which results in the long run under such treatment.

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MELIORATIVE EFFECT OF FOREST SHELTER BELTS ON THE SOILS OF SEMI-DESERTS

A. F. VADIUNINA [1]

The study of unity and interaction between plants and soils in a zonal aspect is one of the main tasks of modern soil science. This paper discusses the results of researches on the effect of forest shelter belts on soils and the influence of soils upon trees.

The objects of study are located on Ergeny, south of Volgograd, where in 1950—1952 experiments have been started by the chair of soil physics and melioration of the Biological Department of the Moscow State University, on growing forest shelter belts, on light-chestnut soils and on a biological melioration of solonetz with the help of shrubs (Vadiunina, 1957; Vadiunina and Verevkina, 1958).

The place of work is located in an area of semi-desert with a dry and continental climate. The annual precipitation is 250—320 mm. The mean annual temperature 7.5°C, that of July +24°C and of January —9.6°C. The relative humidity during the vegetation period is about 40%. Natural vegetation of light-chestnut soils is represented by the Matricaria sp.-Festuca sp. association with a yield of the aerial mass of 7—9 t/ha and of the roots from 20 to 30 t/ha. On solonetzic soils the vegetation consists of Camphorosma-Artemisia pauciflora with yields of aerial mass about 4 t/ha and roots of 9 t/ha. In both types of soils the main mass of roots is concentrated in a layer of 0—30 cm.

Light-chestnut and solonetzic soils have a low humus content, are weakly structured, are characterized by a high density and compactness, a low filtration capacity, which determines their dryness and salinity when moistening is insufficient.

The planting of trees with a well developed root system substantially changes the properties and the regime of these soils. In our research, the roots of the following species have been studied.

Ulmus pennata ramosa on light-chestnut fine-textured heavy soils develops an aggressive root system. At the age of four years its diameter reaches 8 m with a depth about 3m. The soil volume (V) embraced by the

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roots, varies from 7.3 to 63.0 m^3 depending upon the age. At the same age on solonetzic soils treated on these soils with or without gypsum-application, the horizontal development is approximately the same while the development of roots by depth is only about half as long. Correspondingly smaller is the volume: $V = 1.0 - 22\ m^3$. The growth of roots into the depth on solonetzic soils is hindered by a high density of the B_1 horizon and the salinity of the subsolonetz horizon. The elm is a drought-resistant, solonetz- and salt-tolerant species. It is one of the main species used in growing shelter forest belts in semi-deserts.

Fraxinus viridis has a less developed root system compared to the elm. At the age from 2 to 4 years on a light-chestnut soil the diameter of its root system does not exceed 2 m and the depth (h) 1 m. The soil volume (v) is 2—3 m^3 and on solonetzic soils it does not exceed 1.47 m^3. During droughts ash leaves become yellow and dry and even in summer the tree has then an autumn appearance. When it is normally provided with moisture, ash develops well on light chestnut soils, but poorly on solonetzic soils.

Quercus robur—summer form. At the age of 3—4 years on light chestnut soils, when planted in groups or in holes, it produces a root system with a diameter ranging from 0.5 to 3.5 m. Its horizontal development is recorded only in the arable humus horizon. In the compacted horizons B and C, the main root is usually replaced by secondary roots. During droughts and in saline horizons, the roots become brittle, twisted and drop off. The oak can not endure a lengthy soil drought. With an additional humidification in depressions (natural or artificial), oak develops well under semi-desert conditions (Kashinsky, 1952). On solonetzic soils of Ergeny, oak dries up when 2—3 years old.

Acer negunda. At the age of 3—5 years on solonetzic soils it develops a surface root system of an insignificant soil volume. Maples can not endure compact and saline soils. When 4 years old, its top begins to dry-up. Among the shrubs a comparatively large root system is developed by Caragana arborescens, Cotinus coggygria, Elaeagnus angustifolia and, especially, Tamarix Pallasii. At the age of 2—6 years, the diameter of their root system varies within a range of 280—525 cm, the depth from 30 to 180 cm and the volume (V) from 2 to 14 m^3. A comparison of h and V values with the data on the derno-podsolic zone (Kachinsky, 1925) indicates that in the semidesert zone the root-inhabited zone of trees and the V value are much higher.

The density of soils has a great influence on the development of roots. The density in a solonetz sequence measured by Goriachkin-type density gauge with a low moisture content of 9—12% was 47—79 kg/cm^2; it is somewhat lower in a light chestnut soil—41—66 kg/cm^3. The greatest density has been established in the carbonate horizon C of both soils—50—79 kg/cm^2. With an increase in humidity, the density diminishes, in a solonetz, for instance, 2.5—5 times. However, even in humid soils it remains still high—14—34 kg/cm^2. The roots grow mostly during the spring, when the soil is moist.

Soil density is often the cause of a surface development of roots. Roots of some tree species, like ash-leaved maple, for instance, of cherry of the gar-

den species (Kashinsky and Vadiunina, 1950) do not pass the B_1 horizon and develop mainly in the arable layer which results in their drying up.

The application of gypsum to solonetzic soils, considerably diminishes their density and stimulates the development of the root system of many species. It proved especially effective for the development of roots of ash-leaved maple. Thus, with a 15% moisture content, the density measured by Kachinsky density gauge in the 10—30 cm layer happened to be 28—36-kh/sq.cm^2; on a solonetz treated with gypsum (dose 12 t/ha) trees planted on light-chestnut and solonetzic soils produce a bigger mass of roots than the natural grass and semi-shrub vegetation. According to our data, the weight of roots in a layer 0—55 cm under plantations of Fraxinus viridis and Caragana arborescens amounted to 57 t/ha; on virgin land in a layer 0—46 cm-10 t/ha, in other words one third of the former. The tree plantations were 18 years old.

Owing to their greater aggressiveness and larger bulk, the effect of the root systems of trees on the soil is greater than the influence of grass vegetation. In the process of its growth the root system of trees loosens the soil, decreasing its density and compactness. Water permeability of light-chestnut and solonetzic soils under trees, especially if they are already big, substantially increases as compared with the soil of virgin lands and under agricultural cultures (table 1). Average statistical values have been computed

Table 1

Water permeability of soils (mm) during 1 hour (1) and average during 2-6 hours (2) of observation

Soils	Virgin lands		Under agricultural crops		Under plantations			
					up to 5 years		up to 18 years	
	1	2	1	2	1	2	1	2
Light-chestnut fine-textured Heavy soil	50	24	49	28	104	38	222	104
Solonetzic soils	17	4	29	10	54	17	—	—

by 5—25 variants. In each variant, determinations have been subjected to a triple control. During the first hour the permeability reaches its maximum and characterizies mainly the structure of the top horizons of the soil; during the following hours of observation, there is an absorption and infiltration of water into the underlying horizons and the average permeability value under forest plantations during the 2—6 hours is inevitably higher than under grass and agricultural crops. This proves the loosening of deeper soil horizons by the roots. From a meliorative point of view an especially important factor is an increase in water permeability in solonetzic soils under forest belts which, in a virgin and ploughed state, filtrate the water very badly.

The application of gypsum in a dose of 12 tons per hectare increases water permeability. According to observations, in 1960 in a forest belt on solonetzic soil with gypsum application, the permeability during the first hour of observation has been 94, during the 6-th hour 30 mm an hour; on a

soil with no gypsum the corresponding figures were 89 and 12 mm/h (Youy Tsing-yang, 1963). Inasmuch as the greatest number of roots is near the main root, the greatest permeability (during its determination) is near the root as compared to the permeability in the interrow space. The effect of forest shelter belts on the permeability value of the soil depends upon the nature of the root system. When oak is planted by group sowing (thickness 36 plants per one sq. meter) it loosens well the soil by its tap roots. For this reason, permeability is higher in the hole than under an elm or an ash. The elm loosens the soil better than the ash. The elm has a more aggressive root system, consequently permeability under this tree is greater. Owing to the dryness of the climate and of the soils, the life of forest shelter belts in a semi-desert is possible only with an additional humidification by an accumulation of snow in a layer of 60—80 cm, which during years of average winter precipitation is recorded only in belts not exceeding the width of 20—30 m. When the belts are 60 m wide such an accumulation of snow takes place only along the edges to a distance of 10—15 m inward. In the centre of the belt there is not much snow accumulated. Owing to a high permeability, the waters of the melting snow are absorbed by the soil, the depth of spring wetting under forest belts during the years of observation (1950—1960) varying from 1 to 3—4 m against 0.5—1 m on virgin lands. Under plantations that are 18—20 years old, the depth of wetting is, apparently, summed up by years and reaches 8 m and more, as indicated by our data and other information (Chernikov, 1951; Lissovin, 1959). Moisture stocks in the soil at the beginning of the vegetation period are higher under forest belts than on virgin lands and under agricultural crops (table 2) and vary greatly by years; the highest figures refer to the humid year 1958 and the lowest to the dry year 1957.

Table 2

Moisture reserves (mm) on virgin lands (1) in the spring and under the Tamarix (2)

Soil layer in m	1957		1958		1960		1961	
	1	2	1	2	+1	2	‡1	2
0—1	175	167	268	300	217	301	251	275
1—2	159	184	165	291	168	290	169	263
2—3	155	194	163	261	165	205	145	267

+ — fallow; ‡ — wheat

In the edge rows of the belts the depth of wetting is higher than in the centre of the belt and the reserves of moisture are greater. In their normal growth forest shelter belts in steppes and semi-deserts (Youy Tsing-yang, 1963; Rode, 1952; Zonn, 1959) consume 450—500 mm. of moisture. The actual expenditure during 1957 for the vegetation period in different variants of the experiment remained within the range of 190—280 mm.

Moisture deficit as compared with the normal consumption was 170—220 mm. Soil humidity drops to wilting moisture and such a state of humidity can last during dry years for 1.5—2 months. The life of the plants is sus-

tained at the expense of moisture in the deep layers of the soil. Only those species can survive and develop, which can tolerate a lengthy atmospheric and soil drought.

During wet years the supply of moisture exceeds consumption. Salts move along with the flow of moisture. There is a rather intense leaching of the first meter in the thickness of the soil and partly of the layer 1—1.5 m deep. The amount of salts drops below the toxicity threshold for many plants—45 t/ha in a 50 cm layer. The application of gypsum at a rate of 8—12 t/ha improving the physical properties of the soil, intensifies the process of leaching (table 3). As pointed out previously along with a desalinization of light-chestnut and solonetzic soils of semi-deserts, in them there are also processes of desolonetzisation and humus accumulation, (Vadiunina, 1957).

Table 3

Mean values of salt reserves in T/ha on virgin land and under forest bealts on gypsified solonetzic soils and with no gypsum

Solonetz	Layers in cm						
	0—50	50—199	100—150	150—200	0—100	100—200	200—300
Virgin land	20	84	122	137	102	232	168
No gypsum	12	28	112	132	41	242	184
Gypsified	14	18	62	105	25	165	182

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SUMMARY

In the report some new data on the interaction of trees, shrubs and soils are presented. Root systems of trees and shrubs make the soil looser and increase water permeability. The meliorative effect and physical properties depend on plant specie and their age.

The layer involved into the active moisture cycle under 10 years forest belts was 200—400 cm, on a virgin light-chestnut soil less than 100 cm and on a solonetz — about 50 cm. Moisture stocks under forest belts are bigger than on virgin lands or under crops. Due to a good airpermeability and deep moistening, soils are leached up to 100—159 cm. The salt stock in this layer decreases from 100—120 up to 25—50 t/ha.

To increase soil fertility forest and schrub meliorative plantantions sould be used in semideserts; on saline and alkaline soils they may be used in dry and irrigation farming.

RÉSUMÉ

On présente dans ce rapport quelques nouvelles données sur l'interaction des arbres, arbustes et sols.

Les sytèmes radiculaires des arbres et arbustes rendent le sol plus friable et augmentent la perméabilité à l'eau. L'effet amélioratif et les propriétés physiques dépendent de l'espèce des plantes et de leur âge.

La couche engagée dans le cycle de l'humidité active sous des bandes forestières de 10 ans est de 200—400 cm, dans les sols vierges châtain-clairs de 100 cm et dans les solonetz — d'environ 50 cm.

Les réserves d'eau sous les zones forestières sont plus grandes que celles dans les terres vierges ou sous cultures.

Grâce à une bonne perméabilité de l'air et à une humectation profonde les sols sont lessivés jusqu'à 100—150 cm. La quantité de sel dans cette couche baisse de 100—120 jusqu'à 25—50 t/ha.

En vue d'augmenter la fertilité du sol, des plantations de forêts et d'arbustes dans des semi-déserts peuvent être utilisées comme plantations amélioratives, celles sur les sols salins et alkalins puvant être pratiquées tant pour les cultures à sec qu'irriguées.

ZUSAMMENFASSUNG

Es werden im Bericht einige neue Angaben über die Wechselwirkung zwischen Bäumen Sträuchern und Böden vorgelegt. Die Wurzelsysteme der Bäume und Sträucher machen den Boden lockerer und erhöhen die Wasserdurchlässigkeit. Die Meliorationswirkung und die physikalischen Eigenschaften hängen von Pflanzenart und-alter ab.

Die in den aktiven Feuchtigkeitszyklus einbezogene Schicht wies unter 10-jährigen Waldstreifen 200—400 cm, auf jungfräulichem licht-kastanienfarbigem Boden weniger als 100 cm und auf einem Solonetz ungefähr 50 cm auf. Die Wasservorräte unter Waldstreifen sind grösser als auf Neuland oder bebautem Boden. Dank einer guten Luftdurchlässigkeit und tiefeld Durchfeuchtung werden die Böden bis zu 100—150 cm ausgelaugt. Der Salzgehalt sinkt in dieser Schicht von 100—120 auf 25—50 t/ha.

Um eine höhere Fruchtbarkeit des Bodens zu erreichen, können Wald- und Sträucherpflanzungen als Meliorationspflanzung auf Halbwüstenböden angewendet werden, wobei diejenigen auf Salz-und Alkaliböden sowhl als Trocken-als auch als Bewässerungskultur betrieben werden können.

DISCUSSION

P. BILLAUX (Maroc) 1. Quelle est la disposition générale de ces ceintures forestières?
2. Y a-t-il également une influence des bandes forestières sur le sol des bandes cultivées?

A. F. VADIUNINA, Les bandes forestières larges de 60 m sont séparées par des bandes cultivées de 300 m de largeur.

Il y a une certaine influence, mais plus faible que sur le sol, des bandes forestières elles-mêmes.

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